World Academy of Science, Engineering and Technology
International Journal of Biomedical and Biological Engineering
Vol:6, No:12, 2012

# Breast Motion and Discomfort of Chinese Women in Three Breast Support Conditions

X.N. Chen, J.P. Wang, D. Jiang, S.M. Shen, and Y.K. Yang



***Abstract*—**Breast motion and discomfort has been studied in Australia, Britain and the United States, while little information was known about the breast motion conditions of Chinese women. The aim of this paper was to study the breast motion and discomfort of Chinese women in no bra condition, daily bra condition and sports bra condition. Breast motion and discomfort of 8 participants was assessed during walking at 5km $h^{-1}$ and running at 10km $h^{-1}$. Statistical methods were used to analyze the difference and relationship between breast displacement, perceived breast motion and breast discomfort. Three indexes were developed to evaluate the functions of bras on reducing objective breast motion, subjective breast motion and breast discomfort. The result showed that breast motion of Chinese women was smaller than previous research, which may be resulted from smaller breast size in Asian women.

***Keywords*—**Breast discomfort, breast motion, breast support conditions, Chinese women.

## I. Introduction

MANY studies related to the effect of physical activity on health benefits showed that physical activity was associated with better health status [1]-[4]. Except for physical activities' benefits in many kinds of diseases, physical activity confers a reduction in risk of breast cancer for women [5]-[9]. However, exercise-induced breast discomfort was reported up to 56% in a survey on average women [10] and 76% in a research on female athletes [11]. It was found that more breast displacement resulted in more breast pain [12], which has been a barrier for women to do exercise [10], [12]. Besides, breast movement means repeated loading on Cooper's ligaments, which can accelerate breast sag [13], the most unexpected result for all women. Breast is supported by ligament and skin which are not strong enough to control breast motion, without any stronger support elements like bones or muscles inside the breast [13]. Appropriate bra was suggested to be a necessary external support to control breast motion and alleviate the risk of sag [12].

Research on breast motion and discomfort in no bra condition, daily bra condition and sports bra condition has been conducted in Australia, Britain and the United States. The study on breast motion and discomfort has been developing quickly during the past decade. The early related research was published in 1975 and 1978, which focused on female athletes' beast motion and discomfort [11], [14]. Then the object of the research was converted to average women [15]. Sports bra was reported to be superior in breast support and pain reduction [12]. The concept of two types of sports bra, compression sports bra and encapsulation sports bra, was first introduced in 1999 [13]. With more than one reference marker used in the test, breast displacement in three directions was studied from 2009 [16]. Breast velocities of three Chinese females were studied [17], while breast displacement and discomfort was not reported. Instead of treadmill running in previous research, the effect of breast support in overground running was also assessed [18]. In spite of lots of data on breast motion and discomfort, the attempt to apply the data to guide sports bra design was fairly new. Breast elevation and compression at the same time in an encapsulation sports bra was proved to reduce more breast discomfort and bra discomfort than standard encapsulation sports bra, though they didn't make any reduction in breast displacement and velocity [19]. Data of breast motion was collected across several treadmill activity levels in no bra condition and wearing bra conditions [20]. This trial was helpful to understand how breast displacement was affected by activity levels and breast support.

Racial difference exists in many aspects. Racial difference was found in thymidylate synthase enhancer region polymorphism among Asian and Caucasian populations [21]. Compared with Caucasians, the bone mineral density of Asian women was significantly lower [22]-[24]. Racial difference was also found in body weight [25], body satisfaction [26] and various aspects of eating, dieting and body image [27]. Unlike large amount of knowledge on breast motion and discomfort in Caucasian women, little was known about the breast motion and discomfort in Asian women. Although several studies related to breast motion of Japanese and Chinese females were published, only breast velocity, acceleration and trajectory were studied. Besides, data in breast motion and discomfort was compared between different breast support conditions; however there was not a definite method to quantify the function of bra on reducing breast motion and discomfort. The main aim of this paper was to collect data on breast motion and discomfort of Chinese women and compare them with previous research. A method with three indexes was first definitely

X.N. Chen is with Fashion • Art Design Institute, Donghua University, Shanghai 200051 China (e-mail: chen_xn@yahoo.cn).
J.P. Wang is with Fashion • Art Design Institute, Donghua University, Shanghai 200051 China (corresponding author, phone:008613764398182; e-mail: wangjp23@yahoo.cn).
D. Jiang is with Fashion • Art Design Institute, Donghua University, Shanghai 200051 China (e-mail:jiangdong77@gmail.com).
S.M. Shen is with Fashion • Art Design Institute, Donghua University, Shanghai 200051 China (e-mail: 422462866@qq.com).
Y.K. Yang is with Fashion • Art Design Institute, Donghua University, Shanghai 200051 China (e-mail: ykydhahaq379@163.com).

introduced to evaluate the function of bra on controlling breast motion and reducing breast discomfort in this paper.

Some research used more than one reference points to get breast motion in three dimensions. The landmarks in these studies were very different. Some of the reference markers were not anatomical landmarks or not in the same skeletal frame, which leads to inaccuracy [28]. In order to keep the accuracy of results, only sternal notch was used as reference position and only vertical breast displacement was calculated in this paper.

## II. Experiment

### A. Participants

Eight physically active female students were recruited from local university. Participants had an average age of 24.6 years (±1.5 years, ranging from 22 to 26 years), body mass of 59.6 kg (±5.1kg, ranging from 51.5 to 66.9kg), height of 1.67m (±3.7 m, ranging from to 1.56 to 1.73m).

Breast size was decided by taking two measurements, under breast circumference (UBC) and full breast circumference (FBC). UBC was the circumference on the level of the lowest point of breast, and FBC was the circumference on the level of nipples. Both measurements were taken by an experienced anthropometrist using a meter tape. A measurement of 67.5-72.5 cm in UBC equaled to 70 band size, 72.5-77.5 cm to 75 band size and so on. A difference of 10 cm between UBC and FBC equaled to an A cup size, 12.5 cm to a B cup size and so on. According to the calculation method, the cup sizes of participants were B and C, with three 70B, three 75B, one 80B and one 85C. All participants were fitted by a trained bra fitter before the day of testing. All participants had no history of pregnancy, breast cancer or breast surgery.

### B. Experimental Design

In order to compare with previous research, the sports intensity was selected as walking at 5km $h^{-1}$ and running at 10km $h^{-1}$ on the treadmill (see Fig. 1). Participant walked and ran in no bra condition, daily bra condition and sports bra condition. With their own bra, each participant took a warm up walking and running on the treadmill at 5km $h^{-1}$ and 10km $h^{-1}$ respectively, no matter if they had experience in exercising on a treadmill. Markers' movement in space was captured by Vicon system (T40, England), which included sixteen 100Hz cameras (see Fig. 2) locating 4m higher than and 3m around the treadmill.

After the familiar period, participants were asked to take off their own bra in the changing room. Markers were attached on their breasts or on the bras. One marker was put on the sternal notch, which was the reference point and used to capture the trunk motion. Trunk motion needs to be extracted from breast motion. Two markers were pasted on the nipples to get breast motion. It had been proved that nipple could be used as a good indicator of breast motion [28].

Daily bra and sports bra used in the experiment were both common bras. Daily bra (see Fig. 3 (a)) was purchased from Wacoal and sports bra (see Fig. 3 (b)) purchased from Nike in Shanghai area. The sports bra has both compression and encapsulation features.

The original point of the laboratory coordinates system was at the front-right corner of the treadmill. Medial/lateral direction was taken as X axis, anterior/posterior direction was taken as Y axis, and vertical direction was taken as Z axis. To make sure steady breast motion was captured, data was collected after about 30s. Markers' coordinates were recorded for 5 treadmill cycles in each bra condition. Participants rested for about 5 minutes between two experiment conditions.

Fig. 1 Treadmill housed with force platform

Fig. 2 Vicon camera

(a) (b)

Fig. 3 Daily bra and sports bra used in the testing

(a) Daily bra. Purchased in Wacoal, with outside cup made of 100% polyester, inside cups made of 75% polyester and 25% cotton, outside wing made of 79% nylon and 21% spandex, and inside wing made of 86% nylon and 14% spandex; (b) Sports bra with both compression and encapsulation features. Purchased in Nike, with front part made of 92% nylon and 8% spandex, back part made of 100%, front lining made of 100% nylon, back lining made of 89% nylon, and pad made of 100% nylon

After completing the walking and running on the treadmill, every participant gave their perceived breast motion and discomfort by using a VAS of 1 to 10, with 1 being no breast discomfort or no breast motion, and 10 being extreme breast discomfort or extreme breast motion.

### *C. Data Analysis*

The coordinates of markers was captured by Vicon and processed in Visual 3D (Version 3.79.0), then the data were smoothed and low pass filtered at 6 Hz. Sternal notch was the only reference point and used to stand for trunk motion, so the motion of six degrees of freedom cannot be eliminated. For this reason, only vertical breast displacement was analyzed in this paper. The displacement of sternal notch was subtracted from nipple markers' motion to obtain vertical breast displacement relative to the body. Vertical breast displacement relative to the trunk was calculated and averaged between two nipples and during five gait cycles, with one gait cycle being between two right heel strikes to the treadmill. The normality of all variances was checked through Kolmogorov-Smirnow and Shapiro-Wilks tests in SPSS. Repeated measures ANOVA followed by LSD *post hoc* test was used to assess if there was significance among three breast supported conditions. Subjective data were input into SPSS and analyzed using Kruskal-Wallis tests followed by Mann-Whitney tests. The relationship among objective breast displacement, subjective breast motion and breast discomfort was assessed by Spearman test.

RBV (reduced percentage of controlled breast velocity) [17] was once used to assess the effectiveness of sports bra in reducing breast velocity. Similarly, in order to evaluate bra functions on reducing objective breast motion, subjective breast motion and breast discomfort, three indexes were developed in this paper to quantify bra functions:

Index 1: ROM= (OMN-OMB)/OMN×100%
ROM: Reduced objective breast motion ratio
OMN: Objective breast motion in no bra condition
OMB: Objective breast motion in wearing bra condition
Index 2: RSM= (SMN-SMB)/SMN×100%
RSM: Reduced subjective breast motion ratio
SMN: Subjective breast motion in no bra condition
SMB: Subjective breast motion in wearing bra condition
Index3: RDC= (DCN-DCB)/DCN×100%
RDC: Reduced breast discomfort ratio
DCN: Score of breast discomfort in no bra condition
DCB: Score of breast discomfort in wearing bra condition

ROM, RSM and RDC of daily bra and sports bra were calculated, as well as the difference between them.

## III. Results

### *A. Means and Standard Deviation of Objective Breast Displacement and Subjective Breast Motion and Discomfort*

The objective breast displacement captured by Vicon was 0.010-0.013m during walking and 0.026-0.049m during running; subjective breast motion and discomfort was scored 2.5-7.9 and 2.8-6.5 during walking and 3.8-9.4 and 3.3-8.3 during running respectively (see Table I). There was more breast displacement and perceived breast motion in running than walking, as well as perceived breast discomfort.

TABLE I
Mean (±SD ) of Objective Breast Motion Captured by Vicon and Mean (±SD) of Subjective Breast Motion and Discomfort Scores in Three Breast Support Conditions during Walking at 5km $h^{-1}$ and Running at 10km $h^{-1}$.

| | Objective breast motion(m) | | Subjective breast motion | | Subjective breast discomfort | |
|---|---|---|---|---|---|---|
| | 5km $h^{-1}$ | 10kmh$^{-1}$ | 5km $h^{-1}$ | 10kmh$^{-1}$ | 5km $h^{-1}$ | 10kmh$^{-1}$ |
| No | 0.013 | 0.049 | 7.9 | 9.4 | 6.5 | 8.3 |
| bra | (±0.004) | (±0.011) | (±1.2) | (±0.9) | (±2.4) | (±3.0) |
| Daily | 0.011 | 0.033 | 3.6 | 4.6 | 3.3 | 4.0 |
| bra | (±0.003) | (±0.005) | (±1.9) | (±1.8) | (±1.5) | (±1.3) |
| Sports | 0.010 | 0.026 | 2.5 | 3.8 | 2.8 | 3.3 |
| bra | (±0.002) | (±0.004) | (±2.3) | (±2.4) | (±1.4) | (±1.4) |

### *B. The Difference among Three Breast Support Conditions*

The statistic results showed that sports speed and the interaction of speed and breast support conditions have significant effect on breast displacement ($P<0.05$). LSD *post hoc* test revealed where there was significant difference between three breast support conditions across two sports speeds (see Table II).

There was significance between no bra condition and daily bra condition during running, although no significant difference of breast displacement was found during walking. There was significant difference in breast displacement between no bra condition and sports bra condition during walking and running. No significant was found between daily bra and sports bra, nevertheless.

TABLE II
TEST STATISTIC (P VALUE) OF BREAST MOTION CAPTURED BY VICON AND PERCEIVED BREAST MOTION AND DISCOMFORT.

| | Objective breast motion | | | | Subjective breast motion | | | | Subjective breast discomfort | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5km $h^{-1}$ | | 10km $h^{-1}$ | | 5km $h^{-1}$ | | 10km $h^{-1}$ | | 5km $h^{-1}$ | | 10km $h^{-1}$ | |
| | Daily bra | Sports bra | Daily bra | Sports bra | Daily bra | Sports bra | Daily bra | Sport bra | Daily bra | Sports bra | Daily bra | Sports bra |
| No bra | 0.00223 (0.168) | 0.00390* (0.021) | 0.01632* (0.000) | 0.02250* (0.000) | -3.131* (0.002) | -2.929* (0.003) | -3.427* (0.001) | -3.159* (0.002) | -2.494* (0.013) | -2.819* (0.005) | -2.361* (0.018) | -2.690* (0.007) |
| Daily bra | | 0.00167 (0.280) | | 0.00618 (0.102) | | -1.682 (0.093) | | -1.071 (0.284) | | -0.696 (0.486) | | -1.024 (0.306) |

*Significant difference (P<0.05)

Significant difference in perceived breast motion and discomfort was found between no bra condition and daily bra condition, and between no bra condition and sports bra condition. There was no significant difference between daily bra and sports bra on perceived breast motion and breast discomfort.

### *C. The relationship between Objective Breast Displacement, Subjective Breast Motion and Discomfort*

In walking condition, no significant relationship was found between breast displacement and perceived breast motion (P=0.557), as well as between breast displacement and perceived breast discomfort (P=0.257). However, there was strong relationship between perceived breast motion and perceived breast discomfort (P<0.05) during walking. In running condition, the statistics showed strong relationship between breast displacement and perceived breast motion (P<0.01), breast displacement and perceived breast discomfort (P<0.01), as well as between perceived breast motion and perceived breast discomfort (P<0.01) (see Table III).

TABLE III
CORRELATION COEFFICIENT (P VALUE) OF SPEARMAN ANALYSIS BETWEEN OBJECTIVE BREAST MOTION AND SUBJECTIVE BREAST MOTION AND DISCOMFORT

| | 5km $h^{-1}$ | | 10km $h^{-1}$ | |
|---|---|---|---|---|
| | Subjective breast motion | Subjective breast discomfort | Subjective breast motion | Subjective breast discomfort |
| Objective breast motion | 0.129 (0.557) | 0.246 (0.258) | 0.665* (0.001) | 0.647* (0.001) |
| Subjective breast motion | | 0.699* (0.000) | | 0.695* (0.000) |

*Significant relationship (P<0.01).

### *D. Bra Functions Evaluated by ROM, RSM and RDC*

ROM, RSM and RDC all showed that sports bra was more functional than daily bra (see Table IV). When participants were walking at 5km $h^{-1}$, sports bra reduced 23.1% of breast displacement in no bra condition, 7.7% higher than 15.4% in daily bra condition. When participants were running at 10km $h^{-1}$, sports bra reduced 47.0% of breast displacement in no bra condition, 14.3% higher than 32.7% in daily bra condition. The breast motion control functions of daily bra and sports bra were both more evident during running than walking. The difference of breast motion control function between daily bra and sports bra during running was almost twice the difference during walking, which means sports bra should be first choice when women do acute exercise. The RDC data stated that daily bra and sports bra more than half reduced the breast discomfort perceived in no bra condition. Sports bra reduced more breast discomfort than daily bra while the difference between them was small with 3.0% at 5km $h^{-1}$ and 3.5% at 10km $h^{-1}$.

TABLE IV
THE CALCULATION RESULTS OF ROM, RSM AND RDC OF EACH BRA CONDITION AND THE DIFFERENCE BETWEEN THEM DURING WALKING AT 5KM $H^{-1}$ AND RUNNING AT 10KM $H^{-1}$

| | ROM | | RSM | | RDC | |
|---|---|---|---|---|---|---|
| | 5kmh$^{-1}$ | 10kmh$^{-1}$ | 5kmh$^{-1}$ | 10kmh$^{-1}$ | 5kmh$^{-1}$ | 10kmh$^{-1}$ |
| Daily bra | 15.4% | 32.7% | 60.0% | 56.8% | 50.8% | 56.3% |
| Sports bra | 23.1% | 47.0% | 77.5% | 70.5% | 53.8% | 59.8% |
| Difference* | 7.7% | 14.3% | 17.5% | 13.7% | 3.0% | 3.5% |

*Difference equals to $ROM_{Sports\ bra}$-$ROM_{Daily\ bra}$, $RSM_{Sports\ bra}$-$RSM_{Daily\ bra}$, and $RDC_{Sports\ bra}$-$RDC_{Daily\ bra}$, repectively.

## IV. DISCUSSION

### *A. Compare Results with Previous Research*

Breast displacement at 5km $h^{-1}$ in no bra condition, daily bra condition and sports bra condition were 0.013m, 0.011m and 0.010m respectively, smaller than 0.032-0.062m, 0.011-0.029m and 0.014-0.022m in previous research[29]. Breast displacement at 10km $h^{-1}$ in no bra, daily bra and sports bra conditions were 0.049m, 0.033m and 0.026m respectively, smaller than 0.057-0.097m in no bra condition, 0.040-0.071m in daily bra condition, 0.029-0.035m in compression sports bra condition and between 0.010-0.046m in encapsulation sports bra condition in previous research [29] (see Fig. 4). Considering age and breast size, the participants in this paper were similar with Gehlsen and Albohm's research [30] and Mason et al.'s research [12]. When compared with Mason et al.'s research, breast displacement was smaller both at 5km $h^{-1}$ and 10km $h^{-1}$. The three participants in Mason et al.'s study [12] was 12B, 14B and 14C in Australia bra size, which corresponded to 75C, 80C and 80D in Asia bra size [31]. The breast sizes of participants in this paper were three 70B, three 75B, one 80B and one 85C, whose mean cup size was smaller than Mason et al.'s [12]. Smaller breast size may be the main reason for smaller breast displacement than previous research. When compared with Gehlsen and Albohm's research [30], the breast displacement in sports bra condition was between encapsulation bra condition and compression bra condition, because the structure of sports used in this study had both compression and encapsulation features.

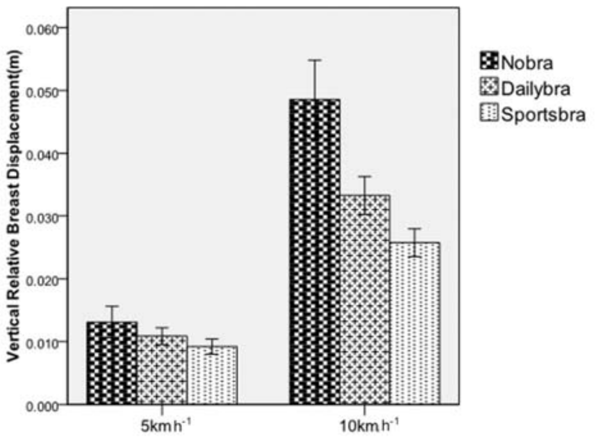


Fig. 4 Mean breast displacement (m) across each breast support condition during walking at 5km $h^{-1}$ and running at 10km $h^{-1}$

*B. Compare the Functions of Sports Bra and Daily Bra on Reducing Breast Motion and Discomfort*

Daily bra and sports bra both had obvious effect on reducing objective breast motion, subjective breast motion and subjective breast discomfort. Statistic analysis showed no significant difference between daily bra and sports bra although there was a trend that sports bra reduced more objective breast displacement and perceived breast motion and discomfort (see Fig. 5) during walking and running. This result was not consistent with previous research which stated sports bra was more functional than daily bra. No significance between daily bra and sports bra may be caused by several reasons: (1) breast size in this research was a little bit smaller than previous ones; (2) daily bra used in this study was of high quality and fitted well by experts; (3) markers was pasted on the rigid cup outside of daily bra instead of breast skin, so bra movement may be captured instead of breast movement.

Although participants felt both daily bra and sports bra could control breast motion effectively, sports bra was thought more efficient than daily bra, which was the same results with the trend showed in objective breast displacement data. However, the daily bra and sports bra were perceived to be less functional during running than during walking, and the difference between daily bra and sports bra descended from 17.5% during walking to 13.7% during running. These results opposed to what objective breast motion data showed. The difference between the breast displacement reduced by sports bra and daily bra was bigger during running than during walking. This inconsistency may be caused by larger perceived breast motion at 10km $h^{-1}$. When participants were walking at 5km $h^{-1}$, breast motion in three conditions was very small, so they felt both bras controlled breast motion very well. However, when they were running at 10km $h^{-1}$, breast motion was much bigger than when they were walking. Although objective breast motion data showed larger percent of breast motion was controlled during running, they still perceived more breast motion than when they were walking. So they felt the bras were not as functional at 10km $h^{-1}$ as at 5km $h^{-1}$. Daily bra and sports bra were both considered more functional on controlling breast motion than what they really were. The sense of security with wearing bras may be the reasons why participants thought the bras controlled more breast motion than they actually did.

Participants didn't perceived big difference at reducing breast discomfort between daily bra and sports bra, though they perceived more than 13% of difference at breast motion.

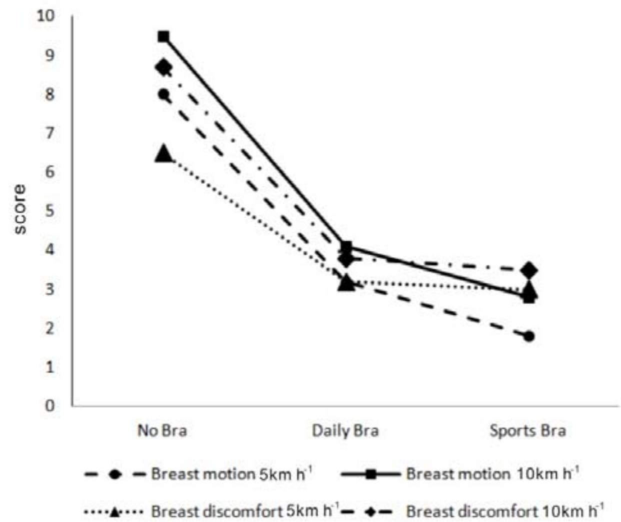


Fig. 5 Mean perceived breast motion and discomfort score across each breast support condition during walking at 5km $h^{-1}$ and running at 10km $h^{-1}$

## V. CONCLUSION

This study collected and analyzed the data of objective breast motion, perceived breast motion and perceived breast discomfort of seven Chinese women in three breast support conditions. Breast motion of Chinese women was compared with the results in previous research, in which participants were Caucasian women. Breast displacement of Chinese females was smaller than that of Caucasian females, which may be caused by common smaller breasts in Asian women. This result was in accordance with the conclusion made by Zhou et al.'s research [27] that larger breast was related with more breast motion. Three parameters were used to define bra's function on reducing breast motion. Although the data of means and the three parameters showed sports bra was a little bit better than daily bra on breast motion and discomfort reduction, statistical analysis revealed no significant difference between sports bra and daily bra. However, these results need to be verified by larger sample size of Chinese females. According to the conclusions, two recommendations were made:

(1) Since Chinese females have smaller breast sizes than their Caucasian counterparts, high quality and well fitted daily bra can satisfy their requirement for breast support for daily activities and exercises at present.

(2) The superiority of sports bra on reducing breast motion

and discomfort did exist. However, the difference between sports bra and daily bra was not so obvious in statistics. Better sports bra which was more appropriate for Chinese females need to be developed to reduce more breast motion and discomfort.

## ACKNOWLEDGMENT

This study was supported by Doctorial Innovation Fund of Donghua University in 2011 (No. BC201117) and Shanghai College Student Innovative Projects (No. X120711202).

## REFERENCES

[1] R.R. Pate, M. Pratt, S.N. Blair, W.L. Haskell, C.A. Macera, C. Bouchard, et al., “Physical activity and public health.” *The Journal of the American Medical Association*, vol. 273, no.5, 1995, pp. 402-407.

[2] A.E. Bauman, “Updating the evidence that physical activity is good for health - an epidemiological review 2000-2003.” *Journal of Science and* Medicine in Sport, vol.7, Supplement no.1, 2004, pp. 6-19.

[3] F.J. Penedo, and J.R. Dahn, “Exercise and well-being: a review of mental and physical health benefits associated with physical activity.” *Current Opinion in Psychiatry*, vol.18, no.2, 2005, pp. 189-193.

[4] D.E.R. Warburton, C.W. Nicol, and S.S.D. Bredin, “Health benefits of physical activity: the evidence.” *Canadian Medical Association Journal*, vol. 174, no.6, 2006, pp. 801-809.

[5] R. Mittendorf, M.P. Longnecker, P.A. Newcomb, A.T. Dietz, E.R. Greenberg, G.F. Bogdan, R.W. Clapp, and W.C. Willett, “Strenuous physical activity in young adulthood and risk of breast cancer (United States).” *Cancer Causes and Control*, vol. 6, 1995, pp. 347-353.

[6] I. Thune, T. Brenn, E. Lund, and M.Gaard, “Physical activity and the risk of breast cancer.” *The New England Journal of Medicine*, vol.336, no.18, 1997, pp. 1269-1275.

[7] B. Rockhill, W.C. Willett, D.J. Hunter, J.E. Manson, S.E. Hankinson, and G.A. Colditz, “A prospective study of recreational physical activity and breast cancer risk.” *Archives of Internal Medicine*, vol. 159, 1999, pp. 2290-2296.

[8] J. Verloop, M.A. Rookus, K. Ven der Kooy, and F.E. van Leeuwen, “Physical activity and breast cancer risk in women ages 20-54 years.” *Journal of the National Cancer Institute*, vol. 92, no.2, 2000, pp. 128-135.

[9] I. Lee, “Physical activity and cancer prevention-data from epidemiologic studies.” *Medicine & Science in Sports & Exercise*, vol. 35, no.11, 2003, pp. 1823-1827.

[10] D. Lorenzten, and L. Lawson, “Selected sports bras: a biomechanical analysis of breast motion while jogging.” *Physician Sports Medicine*, vol.15, no.3, 1987, pp. 128-30, 132-134, 136, 139.

[11] J. Gillette, “When and where women are injured in sports.” *Physician Sports Medicine*, vol. 3, 1975, pp. 61–70.

[12] B.R. Mason, K.A. Page, and K. Fallon, “An analysis of movement and discomfort of the female breast during exercise and the effects of breast support in three case studies.” *Journal of Science and Medicine in Sport*, vol.2, no.2, 1999, pp. 134–144.

[13] K.A. Page, and J.R. Steele, “Breast motion and sports brassiere design. Implications for future research.” *Sports Medicine*, vol. 27, 1999, pp. 205-211.

[14] C. Haycock, G. Shierman, and J. Gillette, “The female athlete - does her anatomy pose problems?” in *Proceedings of American Medical Association 19th Conference on the Medical Aspects of Sports*, Monroe, 1978, pp. 1-8

[15] L. Lawson, and D. Lorentzen, “Selected Sports Bras: Comparisons of Comfort and Support.” *Clothing and Textiles Research Journal*, vol. 8, 1990, pp. 55-60.

[16] J.C. Scurr, J.L. White, and W. Hedger, “Breast displacement in three dimensions during the walking and running gait cycles.” *Journal of Applied* Biomechanics, vol. 25, 2009, pp. 322–329.

[17] J. Zhou, W. Yu, and S. Ng, “3D dynamic analysis of breast without and with a sports bra.” In *Proceedings of the 17th World Congress on Ergonomics*, Beijing, 2009, pp.1-13.

[18] J.L. White, J.C. Scurr, and N.A. Smith, “The effect of breast support on kinetics during overground running performance.” *Ergonomics*, vol.52, 2009, pp.492–498.

[19] D.E. McGhee, and J.R. Steele, “Breast elevation and compression decrease exercise-induced breast discomfort.” *Medicine & Science in Sports & Exercise*, vol. 42, 2010, pp. 1333–1338.

[20] J.C. Scurr, J.L. White, and W. Hedger, “Supported and unsupported breast displacement in three dimensions across treadmill activity levels.” *Journal of Sports Sciences*, vol.29, no.1, 2011, pp. 55–61.

[21] S. Marsh, E.S.R. Collie-Duguid, T. Li, X. Liu, and H.L. Mcleod, “Ethnic variation in the thymidylate synthase enhancer region polymorphism among Caucasian and Asian populations.” *Genomics*, vol.58, 1999, pp.310-312.

[22] L.K. Bachrach, T. Hastie, M.C. Wang, B. Narasimhan, and R. Marcus, *The Journal of Clinical Endocrinology & Metabolism*, vol.84, no.12, 1999, pp. 4702.

[23] G.S. Bhudhikanok, M.C. Wang, K. Eckert, C. Matkin, R. Marcus, and L.K, Bachrach, “Differences in bone mineral in young Asian and Caucasian Americans may reflect differences in bone size.”*Journal of Bone and Mineral Research*, vol.11, no.10, 1996, pp.1545-1556.

[24] P.D. Ross, Y.F. He, A.J. Yate, C. Coupland, P. Ravn, M. McClung, and et al., “Body size accounts for most differences in bone density between Asian and Caucasian women.” *Calcified Tissue International*, vol.59, 1996, pp.339-343.

[25] A.J. Hill, and R. Bhatti, “Body shape perception and dieting in preadolescent British Asian girls: links with eating disorders.” *International Journal of Eating Disorders*, vol.17, no.2, 1995, pp.175-183.

[26] J. Wardle, R. Bindra, B. Fairclough, and A. Westcombe, “Culture and body image: body perception and weight concern in young Asian and Caucasian British women.”*Journal of Community & Applied Social Psychology*, vol.3, 1993, pp.173-181.

[27] G.E. Akan, and C.M. Grilo, “Sociocultural influences on eating attitudes and behaviors, body image, and psychological functioning: a comparison of African-American, Asian-American, and Caucasian college women.” *International Journal of Eating Disorders*, vol.18, no.2, 1995, pp.181-187.

[28] X.N. Chen, D. Jiang, and J. P. Wang, “Can nipple be used as a good indicator of breast in breast motion research?” unpublished.

[29] J. Zhou, W. Yu, and S. Ng, “Methods of Studying Breast Motion in Sports Bras: a Review.” *Textile Research Journal*, vol.81, no.12, 2011, pp. 1234-1248.

[30] G. Gehlsen, and M. Albohm, “Evaluation of sports bras.” *Physician Sportsmed*, vol. 8, 1980, pp.88–97.

[31] K. Shin, *Patternmaking for Underwear Design.* Hongkong: Createspace, 2010, pp. 4-5.