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Article

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Vertical Breast Displacement in Asian Women During Exercise: influence of Bra Type, Size and Different Parts of the Breast

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Abstract

Asian women have smaller breast sizes and greater breast density, which suggests specific research on their breast kinematics and biomechanics. To investigate vertical breast displacement of Asian women among exercise modalities (rope skipping, walking, jogging, running) in different support conditions (wearing everyday bra or sports bra), and assess the motion between different parts of the breast, seven participants were selected to participate in this study. Five infrared markers were placed on each of their left breasts, and a three-dimensional motion capture system (NDI Optotrak Investigator) was used to collect the data on vertical breast displacement during walking (5 km/h), jogging (7.5 km/h), running (10 km/h) and rope skipping (2 Hz). No significant difference was found in the vertical displacement of different parts of the breast in the two bra conditions. Also, there was significant difference in vertical breast displacement among rope skipping, jogging and running. Breast size did not significantly affect its vertical displacement. The smaller, denser breast appears to reach a threshold of vertical displacement that is similar at high severities of dynamic exercises (jogging, running and rope skipping). The results might be useful for designing special sports bras for Asian women with small breasts or rope skipping participants to improve the shock absorption function.

Keywords

rope skipping, motion capture, sports bra, breast support, women’s health.

1. Introduction

Breast discomfort and even pain during exercise bothers many women, especially women with large breasts. It has been shown that these discomforts were caused by excessive breast displacement [1, 2]. For example, excessive breast displacement may cause damage to the suspensory ligament, loose skin, and shrinkage of the glands, which can lead to or accelerate breast sagging [3]. This kind of breast discomfort might be related to the stretch of the skin around the breast and/or the internal ligamentous or glandular structures of the breast tissue. It was reported that 63% of women in a China cohort had breast pain symptoms, of which 35% believed that exercise was one of the causes of breast pain [4]. Fortunately, increasing the level of breast support (wearing a bra, especially a sports bra) has been repeatedly linked to reduced breast displacement [5-8].

It is believed that understanding breast motion during one kind of exercise is helpful to inform sports bra design and thus alleviates breast discomfort during this kind of exercise [5]. Previous research has found differences in breast motion during a range of exercise modalities, including walking [9], running [10] and jumping [11]. However, knowledge on vertical breast displacement during rope skipping is limited. Rope skipping is a form of aerobic exercise with moderate-to-high intensity [12, 13]. It was reported that rope skipping not only provides a positive effect on physical health, such as protecting vascular, strengthening cardio-function, improving antioxidant activity and losing weight [14-16], but also does not require a lot of space or money, which is suitable to be promoted in densely populated environments like schools and for people with modest incomes [12]. However, the jumping component contained in rope skipping may result in excessive breast displacement [17]. Consequently, it is important to investigate breast kinematics during rope skipping and determine whether extra bra support may be needed to avoid discomfort and pain.

Displacement of the nipple has been used to represent the displacement of the whole breast in a majority of previous research [2, 7, 18-20]. Mason et al. concluded that nipple displacement was greater than other parts of the breasts by observing graphs of the vertical movement of five markers in a no bra condition [21]. Chen et al. [20] confirmed the notion that nipple displacement can be used as a good indicator of breast displacement in a no bra condition because they found that nipple displacement was greater than that of other parts of the breast during running, and was similar to that of other parts during walking. However, some other researchers came to contrary conclusions in wearing bra conditions. For example, Arch et al. reported that maximum marker displacement values occurred either above or below the nipple [22]. Zhou et al. also found that the displacement of the lower breast was reduced more effectively than that of the upper breast and top breast in wearing bra conditions when participants were running at the speed of 7 km/h on a treadmill [23]. This means that there might be differences in the displacement of various parts of the breast in wearing bra conditions; namely,

Participants	Upper-breast circumference/cm	Breast circumference/cm	Under-breast circumference/cm	Band size	Cup size
1	85.0	85.5	75.5	75.0	A
2	84.0	85.0	71.5	70.0	B
3	90.0	90.0	74.0	75.0	C
4	84.5	83.5	72.5	70.0	A
5	90.5	90.0	74.5	75.0	C
6	83.0	84.0	72.0	70.0	B
7	88.0	84.0	70.5	70.0	B

Table 1. Participants' breast measurement data

nipple displacement might not be enough to represent the displacement of the whole breast in wearing bra conditions. More points on the breast might be needed to represent the displacement of the whole breast while wearing a bra.

Compared to Western women, Asian women have smaller breast sizes and greater breast density [24-26]. Chen et al. reported that the most common size for American and Australian women is 75C (for the Chinese bra sizing system), while the average breast size of Chinese women is 75B [24]. Li et al. found that Chinese women had 9.61%, 8.20% and 9.28% higher mammographic breast density than their Australian counterparts in all, pre-menopausal and post-menopausal women, respectively [27]. In the case of the same volume, the higher the density is, the higher the mass is. During the same exercise, higher breast mass means greater bra-breast forces at the same breast acceleration (Newton's second law, F = ma, where F - force, m - mass and a - acceleration). According to McGhee et al., greater bra-breast forces would result in increased breast discomfort [28]. Simultaneously, it was reported that Asian women have similar breast discomfort scores to Western women in a no-bra condition when running at the speed of 10 km/h [20, 29]. These findings suggest that Asian women may not have a lower need for shock absorption in sports bras than Western women. Studies on breast biomechanics in Asian women are not rare, however, little previous research has focused on the effect of breast density on breast biomechanics.

The first aim of this study was to evaluate the effect of breast support on breast motion and discomfort in rope skipping, and compare the results with those of three other exercise modalities - walking, jogging and running. Assessing vertical breast displacement between the different parts of a relatively small breast was the second purpose of this research. Finally, this study also aimed to investigate whether there was a significant effect of breast size on vertical breast displacement for women with small breasts but of greater density. It was hypothesised that rope skipping (with a jump component) would generate more vertical breast displacement, perceived breast movement and breast discomfort than the other three exercise modalities. Besides, like other exercise modalities, vertical breast displacement would be significantly decreased by a sports bra, as compared to an everyday bra. It was also hypothesised that there would be a significant difference in vertical breast displacement between different parts of the breast, and that nipple displacement would be greater than that of the other breast areas. Thirdly, it was hypothesised that breast size would significantly affect vertical breast displacement for women with small breasts, the same as for women with large breasts.

2. Methods

2.1. Participants

All of the participants chosen in this research had a relatively small breast size (lower than D cup according to the Chinese bra sizing system), because it was reported that Asian women tended to have smaller breasts with a higher density [24-26]. Seven healthy active women (mean ± SD (standard deviation)): age = 20±1 year; breast circumference = 86±3 cm; upper-breast circumference = 86±3 cm; under-breast circumference = 73±2 cm; band size = 72±3 cm) who had no history of pregnancy, breast cancer or breast surgery were recruited for this study. The specific measurements of the participants are shown in Table 1. According to the professional bra fitting criteria, each participant was fitted by an experienced bra fit assessor. Two of the participants were cup A (breast circumference minus under-breast circumference was 10-12 cm), three were cup B (breast circumference minus under-breast circumference was 12-14 cm), and the remainnig two were cup C (breast circumference minus under-breast circumference was 14-16 cm).

2.2. Experimental bras

A sports bra (NIKE™, China) (Figure 1) designed for medium intensity exercise was chosen for this experiment. Two sizes of this style of bra, M and L, were used for the trials. The cups of the sports bra were made from recycled polyester and spandex blend fabric (88%/12%). The mesh fabric was made from polyester and spandex blend fabric (80%/20%). Both the front and back sides of the liner were made from polyester (100%).

The structure of the everyday bra chosen for the experiment (COSMO LADY, China), is shown in Figure 2. The cup lining is made from polyester and cotton blend fabric (65%/35%). The wing lining is made from polyamide and spandex blend fabric (84%/16%).

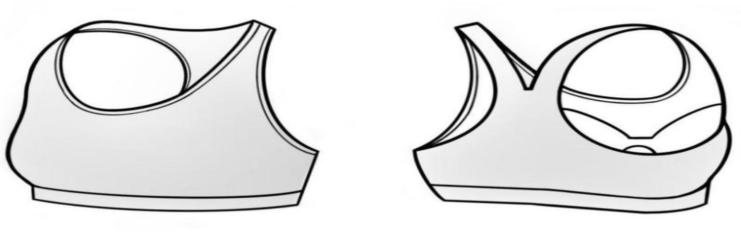

Fig. 1. Structure of sports bra

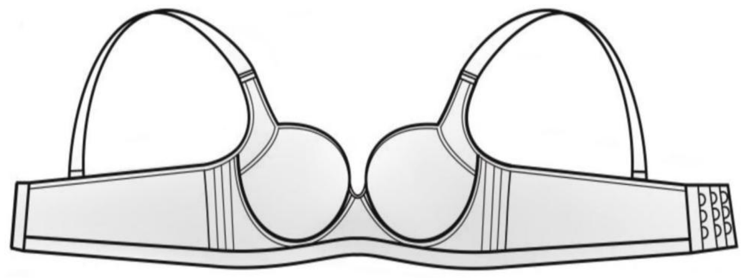

Fig. 2. Structure of everyday bra

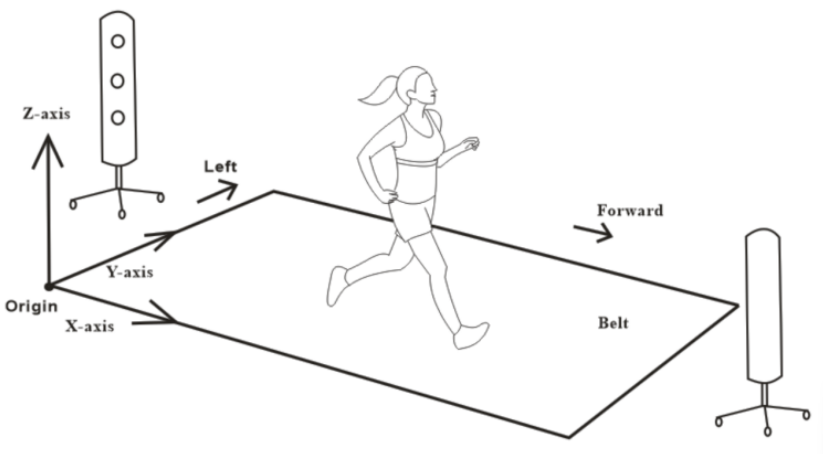

Fig. 3. Coordinate system position and direction calibration diagram

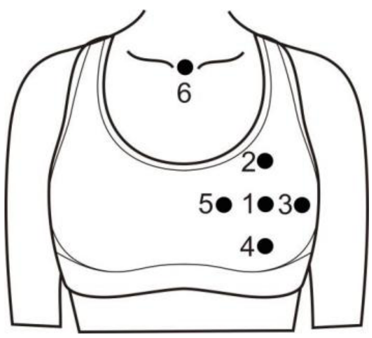

Fig. 4. Marker positions whilst wearing the sports bra
Note: Descriptions of marker position. Marker 1: nipple; marker 2: 3 cm directly above the nipple; marker 3: 3 cm horizontally right of the nipple; marker 4: 3 cm directly below the nipple; marker 5: 3 cm horizontally left of the nipple; marker 6: the suprasternal notch

2.3. Measurement process

This experiment was conducted in the human motion and ergonomics laboratory of the institute. Three-dimensional motion capture systems (NDI Optotrak Investigator) with three infrared cameras (200 Hz) were employed to track the motion of the active tracking markers attached to the body and bra. The whole testing process included the following steps: warm-up, marker attachment and data collection. The origin of the laboratory coordinate system was set in the right rear of the treadmill, which was established with the X-axis positive forward, the Y-axis positive to the left, and the Z-axis positive upward (Figure 3).

2.3.1. Warm-up

To prevent experiment accidents, a period of familiarisation for a few minutes was undertaken before formal experiments. Participants walked or ran at their favourable speed on a treadmill (HP Cosmos Mercury, Germany) and skipped a rope at their favorable frequency overground until they were familiar with the four exercise modalities.

2.3.2. Marker attachment

Assuming breast motion is symmetrical, only left breast motion data were collected. Participants were asked to take off their own bra and put on the experimental bra in the changing room. To quantify breast motion relative to trunk motion, six infrared LED (light emitting diode) markers (20 mm diameter and 3.1 grams each) were attached to predetermined positions on the body with medical tape (Cofoe, China) and on bra points with double-sided tape (Huajiu, China), as shown in Figure 4.

2.3.3. Data collection

All participants completed four exercise tasks in each bra condition. Firstly, participants walked on the treadmill at the speed of 5 km/h while wearing the everyday bra. Data were collected for 60 s in each trial when reaching a steady-state breast motion after 30 s. Then, the same procedure was used to collect breast displacement data during treadmill jogging (7.5 km/h), running (10 km/h) and overground rope skipping (2 Hz). Participants had adequate rest between trials. After all data in the everyday bra condition had been collected, data collection in the sports bra condition was conducted with the same procedure.

2.4. Statistical analysis

The suprasternal notch was used to eliminate trunk motion with six degrees of freedom. The trunk angles (lean) during the four exercises were ignored because they were relatively small in the vertical direction, compared to the horizontal direction [1]. Only the vertical breast displacement was analysed in this paper, because Scurr et al. reported that vertical breast displacement dominates in three-dimensional displacement during high speed running (above 8 km/h) [30]. Vertical breast displacement was calculated via vertical relative breast coordinates, which were the difference between the Z coordinates of the left breast nipple and those of the suprasternal notch. In each gait cycle, minima vertical relative breast coordinates were subtracted from maxima vertical relative breast coordinates to calculate vertical breast displacement in each trial. The mean and SD values were calculated for each of the four exercise modalities in the two bra conditions (everyday bra and sports bra).

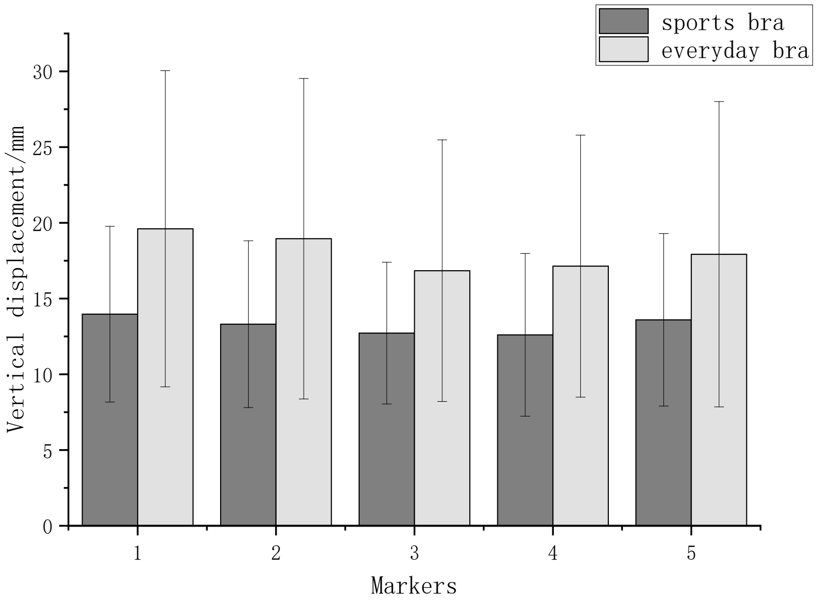

Fig. 5. Mean (±SD) vertical breast displacement at five marked points in each breast support condition

The normality of all data on vertical breast displacement was checked using the Shapiro-Wilk test. A one-way analysis of variance (ANOVA) design with the breast part (five marked points) as the independent variable was used to find whether there was a significant difference in vertical displacement among the different parts of the breast. To determine whether any significant difference exists, Bonferroni post hoc analyses were conducted. A multi-way ANOVA design with three within factors (exercise modality, bra type and breast size) was then conducted to reveal whether there was a main effect on or interactions with vertical breast displacement. Statistical analyses were conducted using the Statistical Package for the Social Sciences (Version 25.0; SPSS Inc., Chicago, IL). The significance level was set at 0.05.

3. Results

3.1. Comparison of the vertical displacement of different parts of the breast

It was found that the vertical movement trajectories of the five points followed a very similar path in the two supported conditions. The vertical displacement of the 5 markers are shown in Figure 5. The mean vertical displacement of the nipple was greatest in each bra condition (sports bra: 14.0 mm; everyday bra: 19.6 mm). The least mean vertical displacement occurred at marker 3 (M3) whilst wearing the everyday bra, whereas this occurred at M4 whilst wearing the sports bra. Nevertheless, the results of the one-way ANOVA showed no significant difference in the displacement of the five marked points ($p > 0.05$).

3.2. Effect of exercise modality on vertical breast displacement

As no significant difference was found among the five markers, the vertical displacement of the nipple was used to represent the vertical displacement of the whole breast. The mean (±SD) of vertical breast displacement was calculated for each of the four exercise modalities in the two bra conditions (Figure 6). There was a dramatic increase in vertical breast displacement from walking (ranging from 4.0 mm to 13.4 mm) to jogging (ranging from 6.6 mm to 35.1 mm). The statistical results showed no significant interaction effect on vertical breast displacement. However, the results of multi-way ANOVA showed a significant effect of exercise modality on vertical breast displacement ($p<0.05$). Bonferroni post-hoc analyses revealed significant differences in vertical breast displacement between walking and each of the other three exercise modalities ($p< 0.05$). Nevertheless, no significant difference was found in vertical breast displacement between running and jogging, running and rope skipping, and jogging and rope skipping.

3.3. Effect of bra type on vertical breast displacement

Vertical breast displacement ranged from 7.4 mm to 25.7 mm in the everyday bra condition, and ranged from 6.5 mm to 18.8 mm in the sports bra condition. The results of multi-way ANOVA in each exercise modality revealed a significant effect of bra type on vertical breast displacement ($p < 0.05$). In other words, the vertical breast displacement while the participants were wearing the everyday bra was significantly greater than when wearing the sports bra.

3.4. Effect of breast size on vertical breast displacement

The breast size of the participants varied from cup A to cup C, which was relatively small. The results of the multi-factor ANOVA showed that breast size had no

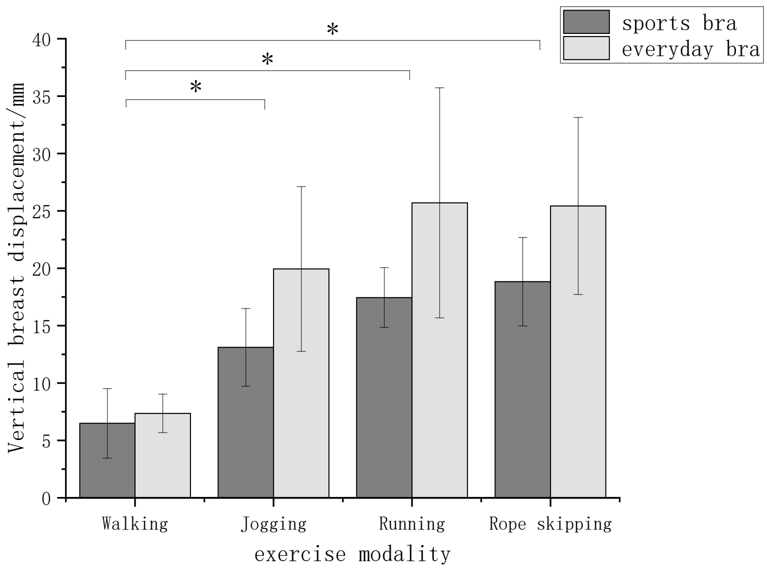

*Fig. 6. Mean (± SD) vertical breast displacement for each of the four exercise modalities in the two bra conditions (n=7). *Significant difference in vertical breast displacement among exercise modalities (p < 0.05)*

significant effect on vertical displacement in each condition ($p > 0.05$).

4. Discussion

In this study, the effect of exercise modality, bra type and breast size on vertical breast displacement in Asian women was investigated. It was found that there was no significant difference among different parts of the breast in each breast supported condition. Furthermore, significant variations in vertical breast displacement were found between walking and each of the other three exercise modalities. A significant reduction was found in vertical breast displacement in the sports bra condition, compared to the everyday bra condition.

4.1. Comparison of the vertical displacement of different parts of the breast

The results of this study showed no significant difference among different parts of the breast, which means that the second hypothesis of this study is rejected. What was found in this study confirmed the results of Mason et al.[21], but was inconsistent with those reported by Arch et al.[22] Arch found that the average maximum marker displacement was greater than that of the marker closest to the nipple, and maximum marker displacement values were located either above or below the nipple medially. This inconformity could be caused by the differences in the bras used in the two studies (the seamless-style bra used in Arch et al.'s study versus the encapsulation bra used in this one), or by the differences in breast density because of participants' ethnicity in the two studies (Caucasian women in Arch et al's study versus Asian women in this one). The finding of no significant difference among breast parts was also in contrast to Lu et al.'s research [8], because the maximum of vertical breast displacement occurred at a point 4 cm directly above the nipple in Lu's research, which might be caused by the different local coordinate system used in the measurement process. This suggests that conclusions drawn under the different coordinate systems may be different.

4.2. Effect of exercise modality on vertical breast displacement

The results showed a significant difference in vertical breast displacement between rope skipping and walking, partially accepting the first hypothesis. Besides, there were significant differences in vertical breast displacement between walking and jogging, and walking and running, confirming the findings by Mason et al. and Scurr et al.'s research [9, 21, 30]. These findings may be explained by the different levels of intensity of the four modalities. The intensity of walking is low, while that of running and rope skipping are both high. When using trunk movement to represent the intensity of exercise, significant differences in vertical trunk movements were found among walking, jogging/running and rope skipping (Figure 7). It is worth noting that the small difference in the degree of trunk forward lean during the four exercises was ignored in this study.

However, no significant difference was found between rope skipping, jogging and running. Namely, when the intensity of trunk motion was higher than jogging, the vertical breast displacement did not increase to comply with the intensity. According to Scurr et al.'s research [30], the vertical breast displacement remained similar when the speed of the running tasks was above 8 km/h in both bra and no bra conditions, which was consistent with this study. Ligamentous structures in the breast limit the motion to some extent, resulting in breast displacement peaking at a certain state instead of continually rising with the landing force. In this study, breast displacement might peak in the jogging condition.

It was also suggested that results of breast motion research analysed in treadmill running conditions (at the speed of 7.5~10 km/h) might be applicable for rope skipping, as no significant difference in vertical breast displacement was found between these two exercise modalities. This finding helps to inform the requirements for breast support garments to reduce breast pain during rope skipping.

4.3. Effect of bra type on vertical breast displacement

The results showed that regardless of the modality of exercise used, vertical breast displacement in the sports bra condition was significantly decreased

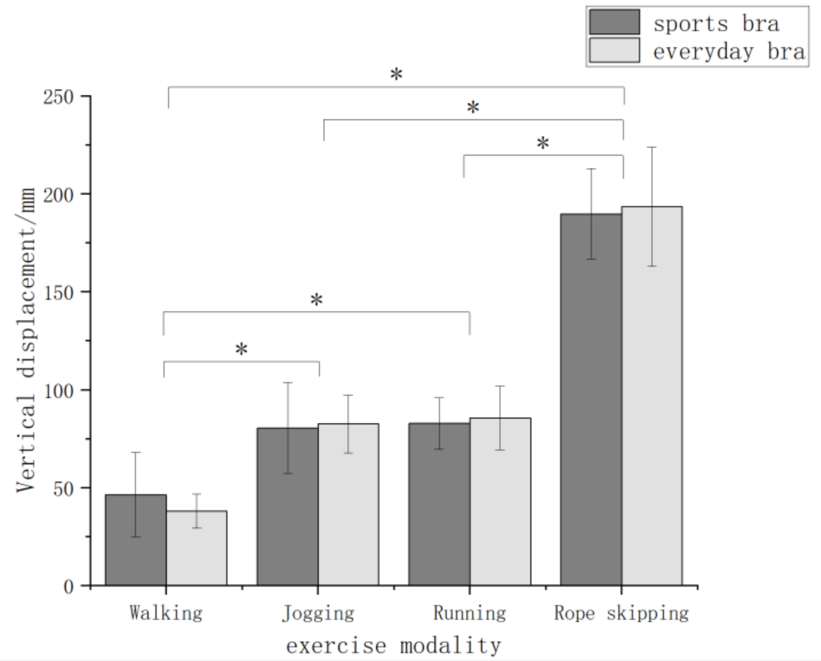

*Fig. 7. Mean (± SD) vertical displacement of M6 (the suprasternal notch) at the four exercise modalities in each breast support condition (n=7). *Significant difference in vertical breast displacement among exercise modalities (p < 0.05)*

compared to the everyday bra condition. That is, in terms of reducing vertical breast displacement, sports bras are more effective than everyday ones. This finding is consistent with previous studies [31, 32]. According to Lu et al.'s research, the tension caused by stretched fabrics and the compressed cup pad made the sports bra more advantageous [8]. During exercise, the kinetic energy of the breast was converted into the tensile energy of the fabric and pad material, along with the compression energy of the pad material [8]. This might be the mechanism by which vertical breast displacement was reduced when wearing a sports bra. The findings also confirmed the notion that wearing a sports bra during exercise is essential for women, as it could reduce breast displacement, and thus relieve the discomfort caused by excessive displacement[2, 21, 29].

4.4. Effect of breast size on vertical breast displacement

The result of the insignificant effect of breast size on vertical breast displacement was in contrast to the third hypothesis, and inconsistent with Boschma et al. and Lorentzen et al., who believed that breast displacement increases as along with the cup size [2, 33]. Although increased breast size results in increased breast mass, breast displacement does not change significantly as breast mass increases if breast density is at a high level [18]. Since participants in this study were Asian women, they have high breast density, which may be the cause of the result. As stiffness is the most important parameter for minimising breast displacement [18], this result may also be explained by the high breast stiffness in the participants. It was reported that Asian women have high density breasts which contain a high percentage of glands inside, leading to high breast stiffness [3, 34]. This finding means that Asian women with small breasts require a similar level of breast support during exercise, irrespective of breast size.

4.5. Strengths and limitations

A limitation of this study is that we only compared the vertical breast displacement, lacking comparisons of the velocity and acceleration of breast movement. Previous research has identified those factors influencing breast discomfort, including speed/acceleration of movement during exercise and ground reaction forces generated by different breast support conditions [19, 35, 36]. Future investigations might consider comparing these three factors between rope skipping and other exercise modalities under different breast support conditions. Besides, a limitation exists in the handling of data. The marked points representing breast motion were not set directly on the breast, but on the surface of the bra. If the bra has significant mass, there might be a relative displacement between the bra and the breasts during exercise, and therefore the results may be skewed. Moreover, it was also recognised that this study was restricted by the small number of participants, which might have led to less representation or larger errors, such as large standard deviation in the mean vertical breast displacements of the five markers. The small number of participants might also have caused the results obtained to be burdened with a high risk of making a mistake when assessing null statistical hypotheses.

In spite of these limitations, up to now, this is the first research to have explore vertical breast displacement during rope skipping, and the first to compare vertical breast displacement during rope skipping with that during walking, jogging and running. The data and findings obtained in this research are therefore essential for the design of special sports bras for rope skipping, which is hopeful for reducing excessive breast displacement and thus alleviating breast discomfort.

5. Conclusion

The results of this study showed that breast size did not affect vertical displacement significantly for small breasts in Asian women. It was suggested that Asian women with small breasts require a similar level of breast support during exercise, irrespective of breast size. Future research is recommended to investigate the effect of other breast parameters to breast motion, such as breast density and breast shape.

Secondly, no significant difference was found in vertical breast displacement between rope skipping and jogging, and between rope skipping and running. It was recommended that findings on breast motion during treadmill jogging (7.5 km/h) or treadmill running (10 km/h) in previous literature could be applied to rope skipping (2 Hz).

Finally, it was found that vertical breast displacement in the sports bra condition was significantly less than that in the everyday bra condition during all exercise modalities, including rope skipping. Hence, it is necessary for rope skipping participants to wear a specialised sports bra with a relatively high level of shock absorption function to alleviate breast motion in the vertical direction.

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