THE BIOMECHANICS OF BETTER BRAS: IMPROVING SUPPORT AND COMFORT DURING EXERCISE

Julie R Steele

Breast Research Australia, Biomechanics Research Laboratory, University of Wollongong, NSW, Australia

The purpose of this paper is to provide an overview of a selected sample of key studies arising from research programs investigating the biomechanics of breast health and sports bra design. Examples have been provided to highlight how relevant research questions pertaining to sports bra design have been developed based on surveys of target cohorts and then how biomechanics principles have been applied to systematically investigate these research questions. Further examples have then been described to show how the scientific results of these applied biomechanics studies have been translated into practice and educational resources to improve bra fit and bra design so that women, irrespective of age, breast size, or disease status, can exercise in comfort and enjoy the health benefits associated with an active lifestyle.

KEY WORDS: breast, breast support, exercise, sports bra

INTRODUCTION: Female breasts contain no substantial anatomical support apart from the skin and fine hair-like Cooper's ligaments. Breast tissue is therefore relatively free to move over the chest wall, particularly during activities involving vertical trunk movement such as running. For this reason, external support, usually in the form of a sports bra, is typically recommended to reduce excessive breast motion and associated breast discomfort and pain when women exercise. Given that as little as 2 cm of vertical breast displacement is sufficient to induce breast discomfort in some females, and that women with large breasts can experience more than 10 cm of breast displacement during running, it is not surprising that many women complain of exercise-induced breast discomfort when not wearing adequate breast support (McGhee et al., 2007). Although well-designed sports bras have been found to be effective in decreasing breast motion during physical activity, a sports bra can only comfortably provide support if it fits a woman properly, irrespective of how well designed it is. Surprisingly, studies have shown that up to 100% of women have been found to be wearing the wrong size bra (Pechter, 1998; Greenbaum et al., 2003; McGhee & Steele, 2006). This is despite the fact that poor bra fit has been linked with upper limb neural symptoms and deep bra furrows caused by excessive strap pressures, non-cyclical mastalgia, and neck and back pain. These symptoms can be so severe as to force women with large breasts to seek reduction mammaplasty or inhibit these women from participating in physical activity (Gehlsen & Albohm, 1980; Lorentzen & Lawson, 1987). Despite the importance of external breast support, particularly for active women, until recent years there has been a paucity of research evidence upon which to design effective sports bras. This lack of evidence, and the subsequent breast discomfort suffered by women due to inappropriate breast support, has been the catalyst for an increasing interest in research programs investigating the biomechanics of breast health. The purpose of this presentation is to provide an overview of a selected sample of key studies arising from these research programs and to highlight how the scientific results of these studies have been translated into practice to improve bra fit and bra design so that women, irrespective of age, breast size, or disease status, can participate comfortably in physical activity and enjoy the health benefits associated with an active lifestyle.

SPORTS BRAS: ONLY A BRIEF HISTORY: Today, sports bras are acknowledged as an essential piece of sporting equipment, not just a fashion accessory or lingerie (McGhee et al., 2008). Interestingly, however, sports bras are a relative new invention, with the first commercially available sports bra only being available as recently as the late 1970's. At this time, an American woman, frustrated by an inability to find a comfortable and supportive bra to jog in, enlisted assistance from a costume designer. Together they sewed together two jockstraps, which formed the foundation of their "Jogbra", which was initially distributed via mail order in 1978 (Bastone, 2013). Release of sports bras onto the market also stimulated the first scientific evaluations of sports bra designs. These initial studies, which first appeared in the 1980's, included biomechanical analyses of the effectiveness of various breast support options in reducing breast motion and enhancing breast comfort (e.g. Gehlsen & Albohm, 1980; Lorentzen & Lawson, 1987; Lawson & Lorentzen, 1990). The first review paper outlining directions for future research in the field of breast motion and sports bra design was released in 1999 (Page & Steele, 1999). Since that time, there has been a rapidly increasing number of biomechanical investigations attempting to better understand bare breasted motion (e.g. Mason et al., 1999; Bridgman et al., 2010; Scurr et al., 2010; Wood et al., 2012; Zhou & Yu, 2012; Zhou et al., 2012) and breast kinetics (Haake & Scurr, 2010; McGhee et al., 2013). There have also been investigations examining how breast biomechanics and discomfort are influenced by external breast support (e.g. Mason et al., 1999; Bowles et al., 2005; Starr et al., 2005; McGhee & Steele, 2010a; Zho et al., 2012a, 2012b; Bowles & Steele, 2013) or the mode of activity (Campbell et al., 2007; McGhee et al., 2007; Scurr et al., 2009; Scurr et al., 2011; White et al., 2011). A comprehensive review paper of studies that have investigated breast motion and sports bra design, including breast biomechanics studies published in English, Japanese and Chinese, is provided by Zhou et al. (2011).

UNDERSTANDING SPORTS BRA DESIGN RESEARCH QUESTIONS: Before investigating the biomechanics of breast support in a laboratory environment, it is imperative to understand the scope and nature of the problem. To achieve this, valid and reliable surveys can be administered to establish and refine relevant research questions, based upon responses from target cohorts. For example, to better understand breast support choices of Australian women when they participated in physical activity and features of sports bras that deter their use by the women, 267 women (mean age = 27.2 ± 4.9 years) completed a self-administered mail survey (Bowles et al., 2008; Bowles et al., 2012). The results revealed that only 41% of respondents wore an encapsulating sports bra when they participated in physical activity. This low sports bra usage rate was primarily due to a lack of awareness of the importance of good breast support during physical activity. It highlighted the need for women to be educated on the importance of wearing a well-fitted and supportive sports bra to decrease excessive strain on breast tissue structures and related breast discomfort (Bowles et al., 2008). Furthermore, the shoulder straps cutting into the shoulders and straps slipping off the shoulders were the two most disliked features of current sports bras. The survey respondents also revealed that perceived tightness of sports bra around the chest was a deterrent for their use (Table 1; Bowles et al., 2012). Such data are vital upon which to formulate well-considered research questions for breast health biomechanics studies, to ensure the results of biomechanics research can be meaningfully translated into useful outcomes for the target cohorts.

Table 1
The top 5 most disliked features in current sports bra designs by survey respondents who wore a sports bra (n =106; n = 22 non-responses; adapted from Bowles et al., 2012).

Bra Feature	Extremely Disliked	Slightly Disliked	Not an Issue
Straps cutting in	36%	32%	33%
Straps slipping	33%	24%	43%
Fasteners digging in	28%	22%	50%
Creeping up	21%	23%	56%
Bra cost	17%	44%	38%

USING BIOMECHANICS TO ENHANCE SPORTS BRA DESIGN: Once a meaningful research question is formulated, standard applied biomechanical data collection and analysis techniques are then used. These techniques are often used in conjunction with psychometric response scales and experimental techniques from other relevant disciplines, in order to systematically investigate factors affecting the fit and design of supportive bras for women to wear when participating in physical activity. For example, custom-designed pressure sensors (Novel, Germany) were used to quantify the pressure exerted on the torso by different bra designs while 22 active women completed maximal cycle ergometer testing in two breast support conditions (a sports bra and no bra). This was followed by submaximal treadmill exercise tests under three randomly assigned breast support conditions (a sports bra, no bra and a fashion bra) while standard spirometry, bra pressure and participant comfort were measured. These unique experiments revealed that wearing a correctly fitted sports bra does not significantly affect maximal exercise performance. Nor does a correctly fitted sports bra appear to affect respiratory function during submaximal exercise, when compared with wearing either a fashion bra or no bra. Although the sports bra imparted more maximal pressure on some participants compared with the fashion bra (Figure 1), no significant difference was found between the comfort ratings for each bra (Bowles et al., 2005). This finding was important because of the survey findings described above, which highlighted that one of the main barriers to women wearing sports bras was that they falsely perceived the tightness of sports bras as possibly impeding their respiratory function and, in turn, their exercise performance (Bowles et al., 2012).

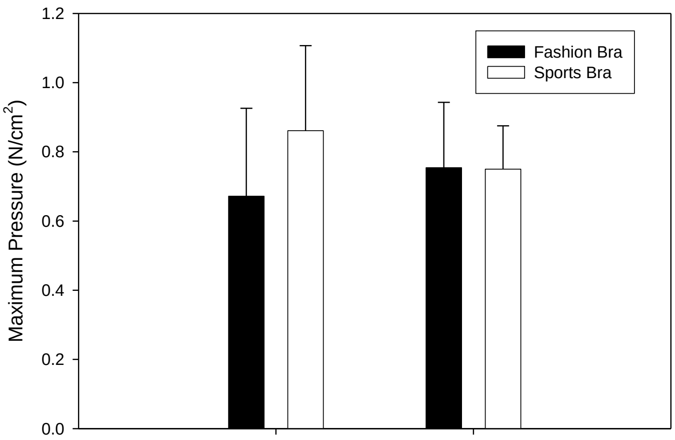

Figure 1: The mean (±SD) maximum pressure recorded under the bra band during submaximal exercise trials for participants with small breasts (n=11) and with large breasts (n=11). A significant interaction ($p<0.05$) was found (*) whereby significantly higher maximal pressures and higher pressures over time were applied to the torso of women with small breasts when wearing the sports bra compared with the fashion bra, although this bra design effect was not noted for the women with large breasts (adapted from Bowles et al., 2005).

In addition to increasing knowledge in the field, well-designed breast biomechanics research can be translated into practice to provide practical breast support solutions. For example, vertical breast displacement of 16 women with large breasts (C+ cup) was monitored, using an optoelectronic motion capture system and video cameras, as the women ran on a treadmill and in 2.4 m deep water (McGhee et al., 2007). Immediately after running, the participants rated their breast discomfort and breast pain and their perceived exertion. Interestingly, the participants perceived deep-water running as a more strenuous but comfortable exercise mode compared to running on a treadmill. This reduction in exercise-induced breast pain when running in water was attributed to an initial elevated breast position caused by the upward buoyant forces associated with the aquatic environment. The buoyant forces decreased the instantaneous vertical breast velocity and prevented the breasts from reaching their end range of motion during the downward breast trajectory. This finding was important as it provided a better understanding of ways to prevent breast discomfort. This, in turn, led to the notion that combining breast elevation with compression in a sports bra would provide significantly increased breast and bra comfort compared to a standard encapsulation sports bra for women with large breasts. This notion was confirmed by comparing breast kinematic data, bra fit comfort, exercise-induced breast discomfort, and bra rankings in terms of preference to wear during running in 20 women with large breasts who ran on a treadmill under three bra conditions: an experimental bra that incorporated both breast compression and elevation, an encapsulation sports bra, and a placebo bra (McGhee & Steele, 2010a). This study formed the basis of an international bra design patent (WO/2010/102348), which has the potential to ultimately enable these research findings to be translated into an evidence-based bra that will assist women with large breasts to exercise in comfort.

Biomechanical investigations have also provided evidence on ways to modify current sport bra designs to enhance wearer comfort. For example, Bowles & Steele (2013) quantified bra shoulder strap pressures, vertical breast displacement, breast pain and shoulder discomfort for 14 women (C+ bra cup) while they ran on a treadmill wearing a sports bra under five strap conditions (no straps, traditional vertical alignment, crossed-back alignment, with and without bra strap cushions). Unexpectedly, inserting commercially available strap cushions under the bra straps was not effective in decreasing the bra shoulder strap pressure due to design flaws that prevented the cushions from adequately increasing the strap-shoulder contact area. However, modifying shoulder strap orientation from a traditional vertical alignment to a crossed-back configuration was identified as a strategy that could alleviate the common problem of bra shoulder straps slipping off the shoulders of the wearer, without decreasing the overall efficacy of the sports bra in providing breast support.

IMPORTANCE OF BREAST SUPPORT FOR CANCER SURVIVORS: Breast biomechanics research can also have substantial benefits for clinical populations, such as breast cancer survivors. Breast cancer is the most common invasive cancer among women worldwide with, on average, 35 Australian women being diagnosed with the disease each day (Australian Institute of Health and Welfare, 2009). Despite an increase in cases, outcomes for women diagnosed with breast cancer have substantially improved. This has lead to a concurrent reduction in mortality rates due to improvements in diagnosis, treatment, and public awareness, among other factors (Australian Institute of Health and Welfare, 2009). Consequently, more women than ever before are living with the effects of breast cancer and its treatment. One of the most effective ways that can enhance the quality of life in breast cancer survivors is physical exercise. However, Gho and her colleagues (2010) revealed that '*I can't find a bra that is comfortable to exercise in*' was ranked as the fourth highest perceived barrier to exercise out of a possible 34 barriers by a sample of 74 breast cancer survivors (mean age = 63.4 ± 10.1 years). A significant 70.3% of the sample reported experiencing bra discomfort during exercise. A recent online survey completed by 482 breast cancer survivors (mean age 53.25 years; range 23-77 years) confirmed this finding whereby the top three barriers to exercise were procrastination, fatigue, and not being able to find a comfortable bra to exercise in (Gho et al., 2013). This finding was important because exercise can address a broad range of quality-of-life issues. Exercise can also enhance improvements in cardiorespiratory fitness, immune function during recovery, self-esteem, and other psychological health parameters in breast cancer patients and survivors (Baldwin & Courneya, 1997; Cheema & Gaul, 2006; McNeely et al., 2006, Ohira et al., 2006). These comprehensive surveys have been the catalyst for a series of biomechanical studies,

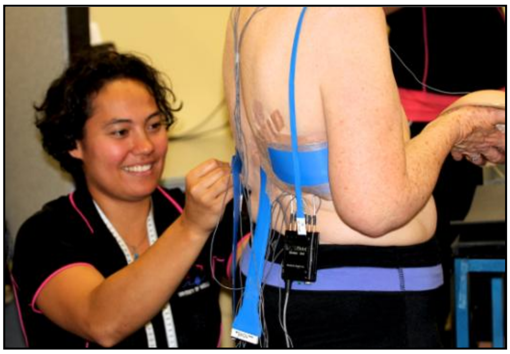

Figure 2: Attaching sensors to a breast cancer survivor to measure the pressure exerted by the bra band, strap and cup

currently in progress, which are examining sports bra design for women living with a diagnosis of breast cancer (Figure 2).

UNDERSTANDING BREAST STRUCTURE TO ENHANCE BRA FIT: Irrespective how well a bra is designed, if it does not fit the wearer, it will not be effective in providing breast support (Page & Steele, 1999). Furthermore, ill-fitting bras are a serious medical issue as they can contribute to numerous negative health outcomes, such as upper limb neural symptoms and deep bra furrows caused by excessive strap pressure; neck and back pain (Kaye, 1972; Ryan, 2000; Greenbaum et al., 2003), as well as poor posture and exercise-induced breast discomfort (Gehlsen & Albohm, 1980; Lorentzen & Lawson, 1987). As highlighted in the introduction to this paper, these symptoms can be so severe as to force women with large breasts to seek reduction mammoplasty (Ryan, 2000; Greenbaum et al., 2003) or inhibit these women from participating in physical activity (Gehlsen & Albohm, 1980; Lorentzen & Lawson, 1987; Mason et al., 1999). For this reason it is imperative that women can select a bra that fits them correctly and provides adequate breast support during physical activity. It has been reported, however, that women have a poor ability to independently select a well-fitted bra. For example, McGhee & Steele (2010) determined the bra size of 104 women (mean age = 43.5 ± 13.2 years; average bra size = 12DD; band size range = 10-24, cup size range = A-G cup; Australian sizes) through self-selection, where the participant tried on several different bra sizes in front of a mirror before selecting a size, and through a variety of bra size measurements (the chest circumference measurement method and the breast hemi-circumference measurement method, both of which are described in McGhee & Steele, 2010b). This was compared to the "correct bra size" as determined by professional bra fitting criteria (Table 2), which were also used to assess the bra fit of each participant's own bra. Results revealed that 85% of the participants were found to be wearing ill-fitting bras and the bra sizes determined by self-selection or using the bra-sizing measurement systems were significantly ($p < 0.001$) different to the correct bra size. The authors concluded that women were found to have a poor ability to independently choose a well-fitted bra, which was not improved by trying on several bras or following bra-sizing measurement systems. It was recommended that the ability of women to independently choose a well-fitted bra could be improved by educating women about professional bra-fitting criteria, which in turn, could assist to promote physical activity and prevent the development or progression of musculoskeletal disorders associated with poor bra fit (McGhee & Steele, 2010b; White & Scurr, 2012).

Table 2

Professional bra fitting criteria (McGhee & Steele, 2010b; McGhee & Steele, 2011).

Band	☐ **too tight**: flesh bulging over top of band, subjective discomfort “feels too tight” ☐ **too loose**: band lifts when arms are moved above head, posterior band not level with inframammary fold
Cup	☐ **too big**: wrinkles in cup fabric ☐ **too small**: breast tissue bulging above, below or at the sides
Under wire	☐ **incorrect shape**: underwire sitting on breast tissue laterally (under armpit) or anterior midline, subjective complaint of discomfort
Straps	☐ **too tight**: digging in, subjective complaint of discomfort, carrying too much of the weight of the breasts ☐ **too loose**: sliding down off shoulder with no ability to adjust the length
Front band	☐ not all in contact with the sternum
Rating of bra fit	☐ **Pass**: no errors or if hooks or straps can be adjusted to allow correct fit ☐ **Fail**: any other ticks

BREAST HEALTH EDUCATION: WHOSE RESPONSIBILITY? In the survey by Bowles et al. (2008), 35% of the respondents with large breasts who did not wear a sports bra during physical activity indicated that they "*had not considered wearing one*". This unexpected result highlighted the need to develop strategies to educate women on the importance of wearing a well-fitted and supportive bra during physical activity to decrease excessive strain on breast tissue and related breast discomfort. Furthermore, as highlighted above, women have been found to have a poor ability to independently choose a well-fitted bra and need education about professional bra-fitting criteria (McGhee & Steele, 2010b). Based on these findings, the educational resource, *Sports Bra Fitness,* was developed (McGhee et al., 2008). The booklet provides an evidence-based resource suitable to educate young female athletes on the importance of wearing well-fitted and designed breast support so they are able to participate in physical activity comfortably. In a cluster-randomised trial, this educational resource was shown to significantly increase the knowledge of adolescent female athletes in relation to bra fit and design issues, as well as successfully changing their bra wearing behaviour (McGhee et al., 2010). In fact, 4 months after receiving the booklet, the experimental group improved their bra knowledge 19% (95% CI 14 to 25) more than the control group. In addition, 39% (95% CI 19 to 54) more of the experimental group passed a Bra Fit Assessment test and 30% (95% CI 11 to 47) more passed a Level of Breast Support test than the control group at 4 months. More recently, an *Exercise and Breast Support Fact Sheet* has also been developed. This fact sheet is a guide for practitioners (e.g. exercise scientists, physiotherapists, coaches, trainers, sports medicine practitioners, etc.) to help them guide their clients and patients in better understanding breast support options during physical activity and how to determine correct bra fit. A *Sports Bra* app has also been developed, based on biomechanical research, to empower women to independently choose a well-fitted and supportive bra that is suited to their exercise needs (McGhee & Steele, 2013).

CONCLUSIONS: Improved bra design and fit is imperative to enable women to participate comfortably in physical activity. Applied biomechanics research studies have provided scientific evidence upon which to formulate recommendations regarding optimal sports bra design and fit for some cohorts of women. These studies have also enabled the development of evidence-based educational resources to assist females to independently choose a comfortable, correctly fitted, supportive bra that will suit their exercise needs. Ongoing research is required, however, to keep investigating innovative breast support strategies so that all women, irrespective of age, breast size, or disease status, can enjoy the health benefits associated with an active lifestyle.

REFERENCES:

Australian Institute of Health and Welfare (AIHW). (2009). Breast cancer in Australia: An overview, 2009. Cat. No. CAN 46. Canberra: AIHW.

Baldwin, M.K. & Courneya, K.S. (1997). Exercise and self-esteem in breast cancer survivors: an application of the exercise and self-esteem model. Journal of Sport and Exercise Psychology, 19(4), 347–358.

Bastone, K. (2013). The history of the sports bra. http://www.ladiesonlysports.com/sports-bra-history/, accessed 11 March, 2013.

Bowles, K-A. & Steele, J.R. (2013). Effects of bra strap cushions and strap orientation on sports brassiere efficacy. Medicine & Science in Sports & Exercise (DOI:10.1249/ MSS.0b013e3182808a21).

Bowles, K.-A., Steele, J.R. & Chaunchaiyakul, R. (2005). Do current sports brassiere designs impede respiratory function? Medicine and Science in Sport and Exercise, 37(9), 1633-1640.

Bowles, K-.A., Steele, J.R. & Munro, B.J. (2008). What are the breast support choices of Australian women during physical activity? British Journal of Sports Medicine, 42(8), 670-673.

Bowles, K.-A., Steele, J.R. & Munro, B.J. (2012). Features of sports bras that deter their use by Australian women. Journal of Science and Medicine in Sport, 15(3), 195-200.

Bridgman, C., Scurr, J., White, J., Hedger, W., Galbraith, H. (2010). Three-dimensional kinematics of the breast during a two-step star jump. Journal of Applied Biomechanics, 26(4), 465-472.

Campbell, T.E., Munro, B.J., Wallace, G.G. & Steele, J.R. (2007). Can fabric sensors monitor breast motion? Journal of Biomechanics, 40(13), 3056-3059.

Cheema, B.S.B. & Gaul, C.A. (2006). Full-body exercise training improves fitness and quality of life in survivors of breast cancer. Journal of Strength and Conditioning Research, 20(1), 14-21.

Gehlsen, G. & Albohm, M. (1980). Evaluation of sports bras. Physician and Sportsmedicine, 8(10), 88-97.

Gho, S.A., Steele, J.R. & Munro, B.J. (2010). Is bra discomfort a barrier to exercise for breast cancer patients? Supportive Care in Cancer, 18(6), 735-741.

Gho, S.A., Steele, J.R., Jones, S.C. & Munro, B.J. (2013). Self-reported side effects of breast cancer treatment: A cross-sectional study of incidence, associations, and the influence of exercise. Cancer Causes and Control, 24(3), 517-528.

Greenbaum, A.R., Heslop, T., Morris, J. & Dunn, K.W. (2003). An investigation of the suitability of bra fit in women referred for reduction mammoplasty. British Journal of Plastic Surgery, 56, 230-236.

Haake, S. & Scurr, J. (2010). A dynamic model of the breast during exercise. Sports Engineering, 12(4), 189-187.

Kaye, B.L. (1972). Neurologic changes with excessively large breasts. Southern Medical Journal, 65(2), 177-180.

Lawson, L. & Lorentzen, D. Selected sports bras: Comparisons of comfort and support. Clothing & Textiles Research Journal, 1990, 8(4), 55-60.

Lorentzen, D. & Lawson, L. (1987). Selected sports bras: A biomechanical analysis of breast motion while jogging. Physician and Sportsmedicine, 15(5), 128-139.

Mason, B.R., Page, K.A. & Fallon, K. (1999). An analysis of movement and discomfort of the female breast during exercise and the effects of breast support in three cases. Journal of Science and Medicine in Sport, 2(2), 134-144.

McGhee, D.M. & Steele, J.R. (2006). How do respiratory state and measurement method affect bra size calculations? British Journal of Sports Medicine, 2006, 40(12): 970-974.

McGhee, D.E. & Steele, J.R. (2010a). Breast elevation and compression decreases exercise-induced breast discomfort. Medicine and Science in Sport and Exercise, 42(7), 1333-1338.

McGhee, D.E. & Steele, J.R. (2010b). Optimising breast support in female patients through correct bra fit. A cross-sectional study. Journal of Science and Medicine in Sport, 13(6), 568–572.

McGhee, D.E. & Steele, J.R. (2011). Breast volume and bra size. International Journal of Clothing Science and Technology, 23(5), 351-360.

McGhee, D.E. & Steele, J.R. (2013). Sports Bra app. Version 1.1, Breast Research Australia, University of Wollongong, Australia (https://itunes.apple.com/us/app/sports-bra/id584698076?mt=8).

McGhee, D.E., Steele, J.R. & Munro, B.J. (2008). Sports Bra Fitness. Breast Research Australia (BRA), Biomechanics Research Laboratory, University of Wollongong, 2008: ISBN 9781741281552.

McGhee, D.E., Steele, J.R. & Munro, B.J. (2010). Education improves bra knowledge and fit, and level of breast support in adolescent female athletes: A cluster-randomised trial. Journal of Physiotherapy, 56(1), 19-24.

McGhee, D.E., Steele, J.R. & Power, B.M. (2007). Does deep water running reduce exercise-induced breast discomfort? British Journal of Sports Medicine, 41(12), 879-883.

McGhee, D.E., Steele, J.R., Zealey, W.J. & Takacs, G.J. (2013). Bra-breast forces generated in women with large breasts while standing and during treadmill running: Implications for sports bra design. Applied Ergonomics, 44(1), 112-118.

McNeely, M.L., Campbell, K.L., Rowe, B.H., Klassen, T.P., Mackey, J.R. & Courneya, K.S. (2006). Effects of exercise on breast cancer patients and survivors: a systemic review and meta-analysis. Canadian Medical Association Journal, 175(1), 34-41.

Ohira, T., Schmitz, K.H., Ahmed, R.L. & Yee, D. (2006). Effects of weight training on quality of life in recent breast cancer survivors: the Weight Training for Breast Cancer Survivors (WTBS) study. Cancer, 106(9), 2076-2083.

Page, K.-A. & Steele, J.R. (1999). Breast motion and sports brassiere design: Implications for future research. Sports Medicine, 27(4), 205-211.

Pechter, E.A. (1998). A new method for determining bra size and predicting postaugmentation breast size. Plastic and Reconstructive Surgery, 102(4), 1259-1265.

Ryan, E.L. (2000). Pectoral girdle myalgia in women: A 5 year study in a clinical setting. *The Clinical Journal of Pain,* 16(4), 298-303.

Scurr, J., White, J. & Hedger, W. (2009). Breast displacement in three dimensions during the walking and running gait cycles. *Journal of Applied Biomechanics*, 25(4), 322-329.

Scurr, J., White, J. & Hedger, W. (2010). The effect of breast support on the kinematics of the breast during the running gait cycle. *Journal of Sports Science*, 28(10), 1103-1109.

Scurr, J., White, J. & Hedger, W. (2011). Supported and unsupported breast displacement in three dimensions across treadmill activity levels. *Journal of Sports Science*, 29(1), 55-61.

Starr, C., Branson, D., Shehab, R., Farr, C., Ownbey, S. & Swinney, J. (2005). Biomechanical analysis of prototype sports bra. *Journal of Textile and Apparel Technology and Management*, 4(3), 1-14.

White, J. & Scurr, J. (2012). Evaluation of professional bra fitting criteria for bra selection and fitting in the UK. *Ergonomics*, 55(6), 704-711.

White, J., Scurr, J. & Hedger, W. (2011). A comparison of three-dimensional breast displacement and breast comfort during overground and treadmill running. *Journal of Applied Biomechanics*, 27(1), 47-53.

Wood, L.E., White, J., Milligan, A., Ayres, B., Hedger, W. & Scurr, J. (2012). Predictors of three-dimensional breast kinematics during bare-breasted running. *Medicine and Science in Sports and Exercise*, 44(7), 1351-1357.

Zhou, J. & Yu, W. (2012). Three-dimensional movements of pert and ptotic breasts. *Journal of Fiber Bioengineering and Informatics,* 5(2), 139-150.

Zhou, J., Yu, W. & Ng, S.-P. (2011). Methods of studying breast motion in sports bras: A review. *Textile Research Journal*, 81(12), 1234-1248.

Zhou, J., Yu, W. & Ng, S.-P. (2012) Studies of three-dimensional trajectories of breast movement for better bra design. *Textile Research Journal*, 82(3), 242-254.

Acknowledgement

This breast cancer research described above research was funded by the National Breast Cancer Foundation with the support of Cancer Australia.