BIOMECHANICAL AND THERMAL COMFORT ANALYSES OF A PROTOTYPE SPORTS BRA

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CHAPTER I

INTRODUCTION

With passage of the Title IX legislation in 1972, there has been a dramatic increase in the number of women participating in sports and regular strenuous exercise. This legislation mandated equal opportunities for girls and women in sports. The increase in women participating in sports and regular exercise may also be attributed to an increasing number of women employed in physically challenging careers. "Between 1970 and 1980, the percentage of women in the Army increased nearly sevenfold, from 1.46% to 9.85%. Today, women make up 10.88% of Army personnel, and with each passing year, more jobs are filled by women" (Gordon, Churchill, Clauser, Bradtmiller, McConville, Tebbetts, & Walker, 1989, p. 1). According to the Astronaut Fact Book, published by NASA (National Aeronautics and Space Administration), six of the 35 astronauts chosen in 1978 for the space team were women (NASA, 1997). The integration of females into previously all male populations signifies that clothing, protective equipment, and sporting equipment, originally sized and designed to accommodate males only, must be modified and redesigned to accommodate larger size and shape variations within the population.

In a September 17, 1998 news release, the American Council on Exercise (ACE) reported a majority of women experience breast discomfort while exercising, causing some to avoid exercise all together (1998). Physical activity causes the breasts to bounce. As the activity increases, so does the bounce and the larger the breasts, the greater the vulnerability. Skin and ligaments (elastic connective tissue) provide a fragile support structure for the breasts that can be compromised by too much bouncing and stretching, and sagging can result (Stamford, 1996). Greater emphasis is being placed on fitness, a positive self-image, and personal enjoyment, rather than focusing primarily on weight loss. The Surgeon General states that physical activity joins the front ranks of essential health objectives, such as sound nutrition, use of seat belts, and prevention of adverse health effects of tobacco (U.S. Department of Health and Human Services, 1996). He concludes that it behooves us, as Americans, to promote exercise in our own unique way. Controlling breast movement during exercise is one important factor to consider in the effort to encourage and promote women's participation in exercise activities.

Fairchild's Dictionary of Fashion defines a bra as a shaped undergarment worn by women to mold and support the breasts (Calasibetta, 1998). Unlike conventional bras that hold breasts up and away from the body, sport bras and tops are designed to hold breasts close to the chest to minimize bouncing, prevent stretched ligaments, and decrease pain from exaggerated breast movement (Walzer, 1990). To accommodate the rapid rise in sports participation by women, sports equipment and specialized apparel have been designed for this segment of the population, including several types of sport bras (Lawson & Lorentzen, 1990).

Sports underwear has gained more visibility of late, both figuratively and literally. "When Brandi Chastain scored the winning shot in a tense, overtime shootout with China in the World Cup soccer final, she did more than just shed her shirt to celebrate the team's triumph. She fired the hopes of sport bra makers everywhere." (Segal, 1999, July 15, p. E01). In that moment of exuberance, Brandi revealed the black Nike sport bra that she had assisted designers in designing. This virtual unveiling brought instant attention and fame to a sturdy undergarment. "The sport bra is the cloth symbol of Title IX's success" (Gerhart, 1999, July 14, p. C01). Ann Gerhart of The Washington Post claims that $230 million worth of sport bras were sold in 1998, up from $205 million the year before.

There are two basic designs of sport bras: compression and encapsulation. The former flattens breasts to redistribute their mass evenly across the chest; the latter supports each breast separately in its own cup (similar to conventional bras). The design engineering of bras must defy laws of gravity and bras are often compared to suspension bridges with support coming from four directions: straps, band, circumference, and two intersecting 180 degree arcs of the cups (Nanas, 1964). To design a bra that accomplishes this engineering feat and is comfortable to wear requires a designer with expertise and a high level of heuristic knowledge, with heuristic knowledge being problem-solving techniques that utilize self-educating techniques (Hardaker & Fozzard, 1997).

Existing research on breast motion and the desirability of specially designed sport bras has confirmed the need for firm breast support, particularly among large-breasted women (Gehlsen & Albohm, 1980; Haycock, 1978; Hunter & Torgan, 1982; Lorentzen & Lawson, 1987; Schuster, 1979). The consensus of these studies suggests that different cup size groups may require different support and design requirements and that the current industry practice of designing bras for various cup sizes in exactly the same way is unacceptable. This poses a real design challenge for the sport bra designer and presents a viable vehicle to improve the health of the nation by affirming our commitment to healthy physical activity on all levels: personal, family, community, organizational, and national.

The design of sporting equipment, including sport bras, is essentially an interdisciplinary activity involving not only implicit designing, but also careful materials selection. Characteristics of the fabric and findings found in a sport bra play an important role in facilitating or impeding function and comfort. "Brassieres evolved as technology provided elastic webbing, two-way stretch fabrics, and zippers" (Farrell-Beck, Poresky, Paff, & Moon, 1998, p. 105). Today, sport bras have improved through the use of performance fabrics, once found only in technical fitness garments or outdoor sports equipment. Articles on new performance fibers read like science fiction novels, with fibers purported to: improve sleep with a scented fiber - CRIPY 65, store solar power - SOLAR-α, and absorb sweat and moisture – WELLKEY (Hongu & Phillips, 1990). Lycra, a man-made elastic fiber invented and produced by DuPont, promotes athletic ability by clinging aerodynamically close to the body without restricting movement. High performance materials have extensively been applied to sportswear, to the construction of sports equipment, and to assist athletes to achieve a better performance.

Purpose

The purpose of this study was to compare a prototype sport bra previously developed using a systematic design process, with two commercially available sport bras through a controlled laboratory wear study under selected environmental conditions. The three sport bras differ in style and fabric composition. Quantitative and subjective measures of support, movement, and comfort were assessed during an exercise protocol using large-breasted female subjects.

Objectives of the Study

The objectives of this study were:

1. To determine the subjects' skin temperature and sweat rate at selected locations, and heart rate during a specific exercise protocol while wearing each garment treatment, and to compare the findings by garment treatment, over time.
2. To determine the subjects' perception of comfort and support during a specific exercise protocol while wearing each garment treatment, and to compare the findings by garment treatment, over time.
3. To determine the amount of breast displacement during a specific exercise protocol while wearing each garment treatment, and to compare the findings by garment treatment.
4. To compare the subjects' perception of comfort and support with the physical and physiological data gathered during the exercise protocols.

Limitations of the Study

1. This study's focus was limited to three sport bras, which consisted of two manufactured sport bras and one prototype sport bra. Therefore, generalities or assumptions cannot be made from this study concerning all sport bras.
2. Participants were limited to six female volunteers who were approximately the same bust size, with brassiere sizes being limited to: 32DD, 34D/DD, or 36C/D, and fell within the age range of 23 to 37 years. Therefore, assumptions cannot be made from this study concerning women of various sizes and ages who wear sport bras.

3. The temperature and relative humidity was controlled using an environmental chamber and was limited to one specified setting and one exercise protocol. Therefore, generalities or assumptions cannot be applied to all environmental conditions or all physical exercise protocols.

Definition of Terms

Absorption is "a liquid taken into the fiber, so that it penetrates the surface and travels throughout the fiber structure" (Watkins, 1995, p. 29).

Adsorption is "a liquid attracted to or held on the outer surface of the fiber, so that it does not penetrate through it" (Watkins, 1995, p. 30).

Biomechanics is "an application of mechanical principles in the study of living organisms. In addressing human movement, biomechanists examine the kinematics of the movement or the technique or form displayed by the performer" (Hall, S., 1991, pp. 1-2).

Bra is "a shaped undergarment worn by women to mold and support the breasts. Usually consists of two cups held in place with straps over the shoulders and elastic in center back" (Calasibetta, C. M., 1998, p. 61).

Clothing Comfort is "the state of satisfaction indicating physiological, psychological, and physical balance among the person, his/her clothing, and his/her environment" (Branson and Sweeney, 1991, p. 99).

Comfort is "the sensation of contented well-being and the absence of unpleasant feelings" (Fuzek and Ammons, 1977, p. 121).

Computerized Cinematography is "the process of using video-based equipment to obtain, process, and analyze movement. The equipment typically consists of high-speed

(200 frames per second) cameras, video processors, digitizers, and computers to analyze the data. This equipment obtains video images by placing reflective devices on the object to be analyzed. The video equipment records the movement of the reflective devices for processing and digitizing by the video processor. The digitized data are computer analyzed with appropriate software" (White and Kaczmar, 1992, p. 201).

Exercise is "the planned, structured, and repetitive bodily movement done to improve or maintain one or more components of physical fitness" (U.S. Department of Health and Human Services, 1996, p. 21). "Exercise has also been defined as physical activity that produces aerobic fitness. To qualify, exercise has to involve large muscle groups of the body (like in the legs), be rhythmic, elevate the heart rate into a 'target zone,' and maintain the elevated heart rate for at least 20 minutes" (Stamford, 2000, p. 117).

General Comfort Sensation is "the subjective statement describing the overall feeling of pleasant or unpleasant body sensations" (Lawson, 1991, p. 7).

Hydrophilic Fibers are "fibers that absorb water readily, take longer to dry, and require more ironing" (Conway, 1997, p. 96).

Hydrophobic Fibers are "nonabsorptive fibers with no affinity for water. It has a low degree of moisture attraction" (Conway, 1997, p. 97).

Kinematics is "the study of the description of motion including considerations of space and time" (Hall, S., 1991, p. 1).

Local Skin Wettedness Sensation is "the subjective statement describing the feeling of moisture at specified anatomical locations during exercise" (Lawson, 1991, p. 7).

Local Thermal Comfort Sensation is "the subjective statement describing the feeling of heat at specified anatomical locations during exercise" (Lawson, 1991, p. 7).

Moisture Regain is "the moisture in a material determined under prescribed conditions and expressed as a percentage of the weight of the moisture-free specimen" (Conway, 1997, p. 131).

Peak Motus® Motion Measurement System is a Windows-based, easy-to-use motion capture system that combines video with exclusive hardware to capture the coordinates of specified moving points. With these coordinates, accurate biomechanical data are produced, including velocities, accelerations, center of mass, distances and angles (Peak Performance Technologies, 2001).

Physical Activity consists of "bodily movement that is produced by the contraction of skeletal muscle and that substantially increases energy expenditure" (U.S. Department of Health and Human Services, 1996, p. 21).

Protective consists of "having the ability to reduce injury from external objects" (ASTM, 1990, p. 342).

Sport Bra is "a bra with built-up straps, coming over shoulders forming a crab-like back, secured by an elastic band around the body and worn for active sports" (Calasibetta, C. M., 1998, p. 63).

Supportive consists of "having the ability to reduce injury from internal factors" (ASTM, 1990, p. 342).

Textile is "a term originally applied only to woven fabrics, now generally applied to fibers, yarns, fabrics, or products made of fibers, yarns, or fabrics" (Kadolph and Langford, 1998, p. 5).

Thermal Comfort is defined as "that condition of mind which expresses satisfaction with the thermal environment" (Fanger, 1981, p. 221).

Wickability is "the property of a fiber that allows moisture to move rapidly along the fiber surface and pass quickly through the fabric" (Conway, 1997, p. 249).

Wicking is "the ability of clothing structures to transport liquid water by capillary action" (Fourt and Hollies, 1970, p. 126).

CHAPTER II

LITERATURE REVIEW

According to Lawson (1991), studies pertaining to supportive sport bras have generally fallen into two categories: (1) informal survey debates which discuss whether specially designed sport bras are necessary, and if so - which styles are best; and (2) biomechanical studies of breast displacement. Studies in the second category are in limited supply. The majority of articles discussing sport bras, mainly performance reports and "what-to-look-for-in-a-sport-bra" type articles, were found in the popular literature. While studies relating to sport bras were located, studies comparing the performance (relative to comfort and movement) of a prototype sport bra with sport bras that are currently being manufactured were not found. There are three integral components typically considered when addressing thermal comfort: (1) the environment, (2) the person, and (3) the clothing. The review of literature in this study describes factors related to the person and clothing, including: breast anatomy, movement analyses, clothing comfort, and moisture transfer respectively. The most relevant bra movement studies did not reveal environmental information.

Breast Anatomy

The female breast has one primary function, the production of milk to support the growing infant. Society has attached various sexual connotations to the size and attractiveness of female breasts. It is important to know that breast size will fluctuate with the changes in a woman's body and her lifestyle. For example, breasts may increase or decrease with the onslaught of physical training, pregnancy, as well as with weight fluctuation. Anatomically the female breasts lie on top of and are loosely attached to pectoral muscles on the front of the chest. Their support is entirely dependent on the skin, subcutaneous tissue, and a rather flimsy framework of fibrous, semi-elastic bands of connective tissue called Cooper's ligaments. In reality, these fibrous bands are not comparable to ligaments that attach muscles to bone or support joints; they are not nearly as strong or resilient. In fact, the only function these ligaments have is to divide the breast tissue into two lobules from which ducts drain to the nipple during lactation.

Breast fibers act like rubber bands and provide that resilient bounce as women walk, explains Albert M. Kligman, M.D., professor of dermatology at the University of Pennsylvania School of Medicine in Philadelphia (Dollemore, D., Giuliucci, M., Kirchheimer, S., Michaud, E., Torg, E., Wallace-Smith, L., & Wisniewski, M., 1994). Adipose tissue (fat) is separated into multiple, distinct lobules by these ligaments. If the proportion of fibrous tissue is high, ligaments will be strong and not excessively stretched and the breasts will retain their shape. If the proportion of fatty tissue is higher, breasts are heavy and are more vulnerable to the laws of gravity. Without proper support the breast tissue will begin to roll off the chest wall, stretching the Cooper's ligaments and thus permitting the breasts to sag. Dr. Kligman states, "Somewhere between the ages of 30 and 40, the elastic tissue in the breast begins to degenerate"(Dollemore, et al., 1994, p. 438). During this degenerative process, the breast tissue displaces itself under the arm and into the midriff area.

Regardless of age, a bra that supports the breast tissue can prevent premature drooping of breast tissue. Haycock agrees that with advancing age most women's breasts flatten and elongate, but she emphasizes that this happens much later in civilized areas where some supporting garment is worn (Haycock, 1978). The anatomy of the breast clearly indicates the need for adequate support at all times, and especially while participating in strenuous exercise. Actually, research supports that females should wear a style of bra that is comfortable and allows minimal bounce every day, not just during physical activity.

Human Movement

In the past century, photographers utilized still cameras in the study of human and animal movement by taking a series of shots in the attempt to capture the movement to be studied. The type of movement and the requirements of the analysis largely determine the camera and analysis system of choice (Hall, 1991). Human motion analysis systems use marker sets, separately instrumented devices (such as electrogoniometers), and imaging methods ranging from television to video systems (Sampath, Abu-Faraj, Smith, & Harris, 1998). In this section, research studies relating to videography, also called computerized cinematography, and tracking of human movement are discussed.

Methodologies for Measuring Human Movement

Videography, also known as electronic imaging systems, allows researchers to acquire many sequential images that can be analyzed right away or stored for later viewing and analysis. White and Kaczmar (1992) describe videography as the process of using video-based equipment to obtain, process, and analyze movement. Typical pieces of equipment used in this imaging process consist of: high-speed camera (the conventional video recorder is the most widely available and the least expensive), video processor, digitizer, and computer.

Three-dimensional motion characterization can be obtained through the use of cameras using optoelectronic techniques, which incorporate markers positioned on prominent anatomical landmarks of the subjects (Sampath, Abu-Faraj, Smith, & Harris, 1998). A quantitative film or video analysis is usually performed with computer-linked equipment that enables the calculation of movement. Digitizing is a traditional procedure for analyzing a film or video which involves the activation of a hand-held pen, cursor, or mouse over subject joint centers or other points of interest, with the x, y coordinates of each point subsequently stored in a computer data file (Hall, 1991).

Another approach to quantitative analysis of human movement that eliminates the hand-digitizing process involves the attachment of tiny electric lights known as light-emitting diodes (LEDs) or highly reflective markers over the body joint centers. Computer-linked cameras track these special lights or markers, enabling automatic calculation of the quantities of interest (Hall, 1991).

In 1999, James Richards conducted field studies to assess the clinical performance characteristics of seven optical-based and one electromagnetic-based biomechanical measurement system. Commercial instrumentation commonly used to measure whole body motion can be divided into two categories (Richards, 1999). The first category, according to Richards, uses equipment that provides a visual record of body segment positions, while the second category uses magnetic sensors to determine the position and orientation of segments in laboratory space. Richards further divided these image-based devices into categories of passive and active systems depending on the type of markers that each system uses. Passive systems use markers that reflect light back to the sensor while active systems use markers that contain the source of light for the sensors (1999).

The passive marker systems that Richards reviewed included the Ariel system, Motion Analysis' HiRes system, Peak Performance's Motus system, Qualisys' ProReflex system, BTS's ElitePlus system, and Vicon's 370 system. Richards explains that the

> "measurement of the distance between the two markers on the top of the plate provided each system with the requirements of having to generate paths for the markers using information from different camera pairs as the plate rotated throughout the volume. The average measured distance was within 1 mm of the known distance for all but one of the systems. The RMS values for the variability of this measure were less than 3 mm for six out of the seven systems, and the largest error reported by any of the systems was just greater than 1 cm. Data from the plate markers as also used to calculate the angle formed by the three markers. With the device placed on the floor, a camera that viewed the plate from the side would typically only see two markers, as the marker closest to the camera and the bottom plate marker would merge. The configuration of the facility that used the Peak Motus, Ariel, Qualisys, and ElitePlus systems placed cameras in a circular pattern around the volume at equal increments. On average, all systems measured the absolute angle within 1.5° of the actual value. RMS error reported by most of the systems was typically within 3°, which means on average the systems performed quite well. In general, most systems produced better results for the stationary marker when its minimum distance to the rotating marker was greatest. For the Peak Motus and Vicon 370 systems, the error associated with the measurement

of the stationary marker increased as the distance between the rotating marker and stationary markers decreased. It should be noted that tracking time for 4 seconds of data collection, for the passive marker systems, took less than 2 seconds for the Peak Motus, Vicon, and Motion Analysis systems. Richards explains that the "measurement of the distance between the two markers on the top of the plate provided each system with the requirements of having to generate paths for the markers using information from different camera pairs as the plate rotated throughout the volume" (1999).

The Vicon and Peak Motus systems operated in the spatial domain, providing the user with a visual tracing of each marker in space (Richards, 1999). The efficiency of the process and the amount of editing were responsible for the vast majority of time required to produce results. Tracking time and the amount of editing needed were the major differences found between the different systems. Therefore, availability and cost may become the determining factor in choosing the appropriate system for a specific study.

In a research paper written by Hashimoto, Izawa, Yokoyama, Kato, & Moriizumi (1999), a new method that quantifies the overall free movement of animals without markers is described. "This method detects subtle and quick changes of overall movement, and is more sensitive and reliable than other methods which have been developed thus far. Furthermore, the experimental results indicate that this method can be applied to various fields of motion analysis" (Hashimoto, et al., 1999). This new method is accomplished through the following steps: a frame without a subject is stored in a hard disc as a background frame; then frames with an object are stored at specified frequencies. The program reads a frame with an object from the hard disc and extracts the object from the background by subtracting the background frame; in other words, each pixel value is subtracted from the same positioned pixel value of the background.

Another method of measuring joint mobility involves the use of a magnetic tracking device. This 1997 study focused on the manually maneuvered foot motion of thirteen cadaveric foot specimens. Three-dimensional movements of four bones (talus, calcaneus, navicular, and first metatarsal) relative to the fixed tibia were monitored with a magnetic tracking system, which consisted of one three-axis source, four three-axis sensors and an electronic unit (Kitaoka, Luo, & An, 1997). The magnetic source was fixed to the tibia, while the sensors were fixed with acrylic plastic mounting posts to the four bones described above.

Breast Displacement

In regard, to breast displacement, it is not absolute breast motion that matters but motion relative to the trunk (G. Smith, personal communication, April 29, 2000). The greatest relative displacements occur in the vertical direction. The total amount of displacement during each step can be determined by finding the difference between the maximum and minimum positions found (G. Smith, personal communication, April 29, 2000). To determine the motion of the breast with respect to the trunk, reflective markers are placed on the trunk at a location over the clavicle where there will be limited skin motion and on the bra over the nipple area. The motion is recorded either by video or another multiple camera system. The marker positions are analyzed frame-by-frame and combined with calibration information to determine three-dimensional coordinates. The coordinates are processed to determine any kinematic characteristics. Data can then be entered into a spreadsheet format for use with statistics software, such as SAS or SPSS.

Biomechanical techniques have been incorporated into various studies to investigate displacement of the supported and unsupported breast tissue. Haycock, et al., (1978), conducted a film study of five college women walking and jogging on a treadmill wearing their own bras, specially fitted bras, and no bras. These subjects were filmed using a 16 mm movie camera at a rate of 100 Hz (100 frames per second) while walking at 3 mph, and running at 6 mph, on a 1° incline on a treadmill. Markers were placed over the nipples, then each subject was filmed nude, wearing their own bra, and wearing the fitted bra. The range of motion was delineated frame-by-frame depicting curves, which resemble a child's drawing of a bow tie. Each set of depictions forms a graph, which indicates the x and y coordinates of the breast movement frame by frame, and reveals the path of movement that the breast tissue follows. The breast mass appears to move in a sidewise variation of a figure eight, especially without a bra to constrict movement. "The pictures clearly demonstrated that with no bra the breasts especially large or pendulous ones, rose up and then slapped down against the chest wall with considerable force at each complete step" (Haycock, Shierman, & Gillette, 1978, p 7). This research revealed that wearing a bra is advisable for women who are physically active. The specially fitted bras showed a marked improvement in the restriction of both vertical and lateral breast displacements (Haycock, Shierman, & Gillette, 1978).

In 1980, Gehlsen & Albohm conducted a similar study using a Locam camera (100 Hz) to film jogging subjects and a Van Guard Motion Analyzer to evaluate the film. As seen in the previous study, standard biomechanical procedures were used to determine the linear displacement, velocity, and acceleration. Again, one marker was placed over the bra at the breast point, while another marker was placed on the center of the left clavicle to determine the vertical and horizontal displacement of the body and the breast. The difference between the body and the breast displacement values, during one running stride, was calculated and considered to be the displacement allowed by each bra. This one study contained three phases. Phase 1 endeavored to learn whether sport bras differ in the amount of support they provide. In this phase, forty female athlete volunteers (divided into four groups based on cup size – A, B, C, and D) wore eight different sport bras, while jogging on a treadmill at 6 mph on a flat grade. The mean vertical displacement of the breasts differed significantly by bra (Gehlsen & Albohm, 1980).

"Phase 2 endeavored to learn the normal range of breast movement for comfort during jogging" (Gehlsen & Albohm, 1980, p. 94). In this phase, twenty female athletes were filmed while wearing their own bras and running on a treadmill at 7 mph. Of these twenty female athletes, ten (five wore size B, two wore C, and three wore D) reported experiencing breast discomfort in the past and ten (nine wore size B and one wore size D) had not. The discomfort group's breast mass was reported to be 18% greater than the non-discomfort group's. This study revealed that vertical displacement between those who had experienced breast discomfort and those who had not, was not significantly different. Velocity of breast movement showed no significant difference when considered alone, but there was a significant difference when the mass of the breast and the velocity were considered together.

Phase 3 of this same study measured the effectiveness of additional binding of the breasts while jogging. In this phase, twenty female athletes (cup size not reported) were filmed four times while wearing two selected sport bras (with and without a 4-in. elastic wrap over the bra) and jogging on a treadmill at 6.5 mph. After completing all three phases, Gehlsen & Albohm (1980) found that the binding prevented approximately 45% of the movement and concluded that the mass of the breast, in conjunction with the velocity of its movement, may be related to discomfort while jogging.

In 1987, Lorentzen and Lawson conducted a biomechanical study using a 16 mm Photosonics Action Master camera (100 Hz) and a Lafayette Motion Analyzer. Body reference points were marked. Fifty-nine subjects were filmed jogging nude and while wearing selected sport bras on a treadmill at 6 mph on a flat grade. The objectives of this study were to: (1) determine and compare vertical breast displacement for women with small (A cup), medium (B and C cup), and large (D cup) breasts, (2) compare the difference in vertical support provided by selected sport bras in each size range, as well as across subjects, and (3) compare design features from each bra and identify positive design features for future design recommendations. "The D cup-size group displayed more mean vertical displacement in the nude than either the A, B, or C groups. This finding supports the idea that vertical displacement of the breast could potentially be a more serious problem for active women in the D group, and that designing sport bras specifically for size D (and larger) women is important" (Lorentzen & Lawson, 1987, pp.136-139). Results of this study demonstrated that the larger the breast the greater the vertical displacement.

In 1994, Boschma, Smith, & Lawson conducted a study to determine the effects of breast support on stride rate (SR), stride length (SL), vertical center of mass displacement (VCMD), and vertical breast motion (VBM). "Three conditions of breast support were used: 1) non-support, 2) moderate support, and 3) full support" (Boschma, et al., 1994, p. S99). Ten female recreational runners with a breast cup size of either B or C, aged 18-58 years, were filmed while running on a treadmill in all three conditions. Video was collected at the end of 5 minutes of running, except for the non-support condition, which was collected after one minute of running due to the intolerable condition. According to Boschma, et al., (1994), three-dimensional video analysis tracked each subject's breast and trunk motion for 10 cycles. Boschma, et al., (1994) found that vertical breast motion (VBM) was significantly different across support levels for heelstrikes of the foot on the same side as the breast (SVBM) and for heelstrikes of the contralateral foot (CVBM), ($p<.0001$). "Despite substantial differences in breast motion between the 3 conditions of breast, the kinematic variables stride rate (SR), stride length (SL), and vertical center of mass displacement (VCMD) did not substantially change" (Boschma, et al., 1994, p. S99).

Comfort Perception of Brassieres

The biomechanical studies previously discussed, which focused on breast motion and the evaluation of specially designed sport bras to provide support, substantiated the need for firm breast support, particularly among full-breasted women, to minimize breast discomfort during strenuous activity (Gehlsen & Albohm, 1980; Haycock, 1978; Haycock, et al., 1978; and Lorentzen & Lawson, 1987). Soft materials and a well fitting design are important characteristics of any bra. In addition to these characteristics, perceived comfort of sport bras requires additional considerations. This section focuses on perception of bra comfort.

Haycock (1978) claims that proper breast support and protection for the female athlete has been neglected for too long. Even minor problems in this sensitive part of the female anatomy can prove disabling to an athlete (Haycock, 1978). Haycock advocates that women wear a good supporting bra during exercise; as well as during their menstrual cycle, when most women experience some discomfort in their breasts based on hormonal stimulation (1978). According to Haycock, large breasts pose a problem in almost all sports and states that these women definitely require a good supporting bra. Haycock (1978) concludes that an adequate bra should: 1) provide firm support, 2) limit motion of the breast relative to the body, 3) be made of absorptive, non-abrasive, non-allergenic material, and mostly non-elastic material, 4) be supported by wide, non-elastic, and non-slip shoulder straps, and 5) have capacity for insertion of padding.

A questionnaire, designed to discover breast pain and irritation related to wearing bras, was used to survey 85 intercollegiate female athletes in Hunter & Torgan's 1982 study. This questionnaire did not reveal any relationship between the incidence of breast pain and the type of bra (Hunter & Torgan, 1982). An important factor to realize when reviewing this particular study is that only 10% of the athletes questioned wore a sport bra. The athletes did reveal that they looked for inexpensive bras that were easy to launder. Desirable design features identified included: seamless cups, nonirritating clasps, absorbent material, and non-slip shoulder straps.

In a survey regarding sports related breast injuries and/or pain, 56% of the subjects experienced sports related breast pain or discomfort, with the most common causes of pain being breast motion and premenstrual syndrome (Lorentzen & Lawson, 1987). Incidence of pain was similar for all cup sizes, but subjects wearing smaller cup sizes (A and B) attributed the pain primarily to premenstrual symptoms, whereas, the subjects wearing larger cup sizes (C and D) complained that most of the pain stemmed from excessive motion (Lorentzen & Lawson, 1987).

In 1990, Lorentzen and Lawson repeated a version of their 1987 study to compare comfort and support of selected sport bras. They examined both quantitative motion displacement data and post-exercise evaluations of perceived support and comfort for seven marketed sport bras. The objectives of this study were to: (1) evaluate seven selected sport bras on support and comfort for women of A, B, C, and D cups sizes, (2) subjectively evaluate the relationship between comfort and support for each of the seven bra styles, (3) examine the relationship between the subjective measures and the data from the videos, and (4) identify design features of bras that provide both support and comfort. Immediately following the exercise session, subjects completed a questionnaire that addressed their perception of comfort and support during exercise. Although there were exceptions, the correlation coefficients indicated that bras that received higher scores on comfort were scored lower on support. The bra scoring highest in perceived comfort was constructed of medium modulus, soft cotton/spandex blend knit fabrics, had no fasteners, and had a cross-back or Y-back strap configuration that minimized slipping of straps during exercise. The bras that scored highest in perceived support were constructed of high modulus knit fabrics with low extensibility, the straps were stabilized with non-elastic materials to allow minimal stretch and designed to compress the breasts against the chest wall. No single style of sport bra was found superior on all criteria: control of vertical breast displacement, subjective comfort ratings, and subjective support ratings.

The results from the above noted study appear to indicate that perception of support and perception of comfort, although interrelated, may be more complex than just restricting vertical motion of the breast tissue. Most researchers agree that several important parameters interact to influence an individual's feeling of comfort or discomfort regarding clothing (Branson, Abusamra, Hoener, & Rice, 1988; Fuzek, 1981). Perception of bra performance is multi-dimensional.

Clothing Comfort

General comfort has been defined as "the sensation of contented well-being and the absence of unpleasant feelings" (Fuzek and Ammons, 1977, p. 121). Slater describes general comfort as "a pleasant state of physiological, psychological, and physical harmony between a human being and the environment" (1985, p. 4). The definition of comfort is ambiguous at best and researchers are continually striving to understand and explain the perception through various comfort models. "Research on clothing comfort has changed from the study of individual characteristics of fabrics and fibers to the holistic approach of evaluating a garment system and its relationship to a human body" (Searle, 1990, p. 3).

"Garment comfort is neither a physical property nor an abstract image. It is a composite perception that must refer to one or more individuals, to a specific environment, and to a preference of one alternative over another. The more individuals perceive the same preference under the same conditions, the greater the justification to speak about garment comfort and to analyze the composite responses for specific comfort factors. Properly conducted wear and preference tests are powerful research tools" (Hyun, 1989, p. 5).

Professor Norman R. S. Hollies, University of Maryland, is well known in the field of human perception and he has developed a sensory evaluation technique that has been applied to the area of clothing comfort. His technique, which is called 'Human Perception Analysis', is a method for eliciting how and when a subject perceives various features (Hollies, Custer, Morin, & Howard, 1979). Humans draw perceptions from life experiences using all of their senses and this forms the basis from which they ultimately make their decisions. Therefore, the perception of comfort is as varied as individuals and their life experiences. Although, subjective testing in science is often perceived as a problem, the subjective data of human sensory perception is important and necessary because only people can tell what they perceive (Hyun, 1989). Ultimately, it is a person's perception of comfort that will be the deciding factor as to whether or not they will wear a specific garment.

Human Perception Analysis Procedures include asking participants to describe the intensity of sensations they experience at specified intervals of time (e.g. every 5 min.), using a provided reference list of terms, during repeated experiments. According to Hollies, participants in a 1979 shirt study did not have a problem in rating the intensity of any sensation experienced using the scale of 4-partially to 1-totally. "The study on shirts worn by men and women both outdoors and indoors revealed that strong sensations were noted when mild or heavy sweating occurred, and during modest excursions of warming or chilling following the inception of sweating" (Hollies, et al., 1979, p. 557). According to Hollies, research indicates that for many normal wearing conditions in which there is no perspiration, the differences between garments at the perception level are quite small (1979).

In a 1990 study, Searle evaluated and compared the comfort properties of six lingerie fabrics, these fabrics included: woven cotton, silk, polyester; knitted Hydrofil® nylon, 50/50 Hydrofil®/nylon blend, and Antron III® nylon. Subjects evaluated the comfort of slips made from these fabric when worn alone, under a polyester dress (hydrophobic), and under a cotton dress (hydrophilic), while walking and sitting in an environmental chamber (Searle, 1990). When asked to state a preference for slips within the knit or woven group, the subjects expressed a preference for the polyester slip. This research reinforces the idea that clothing comfort is dependent on fiber characteristics, fabric properties, garment design and fit, and the environment in which the clothing is worn (Searle, 1990).

In a 1989 study, four female subjects participated in a wear study to better understand skin sensation (Hyun). Participants in this study exercised on a stationary bicycle, while wearing two different kinds of leotards (nylon and cotton), in an environmental chamber, which controlled the temperatures and humidity microclimate. The operator introduced windy and wet conditions randomly. Comfort ratings were requested every fifteen minutes by the operator using the Comfort Descriptor Rating Sheet provided by the operator for the participants. Results of this study reveal that both fiber type and various environments influence garment comfort (Hyun, 1989).

"Research related to the discomfort sensation associated with small amounts of water in the skin-clothing interface has been carried out with moisture from sweating or from added moisture simulating the clothing contact sensations" (Hyun, 1989, p. 33). In their book, Clothing Comfort, Hollies and Goldman conclude that 3-5 % added moisture could stimulate sensations of discomfort (1977). It is generally accepted that the major factors that influence clothing comfort are the movement of heat, moisture, and air through fabric (Hyun, 1989).

Moisture Transfer

"Water plays a significant role in heat loss, not only because it can destroy the effectiveness of insulations such as down, but also because it can generate evaporative heat loss and rapid conduction of heat away from the body" (Watkins, 1995, p. 29). "The amount of moisture which textile fibers are capable of absorbing affects their use in clothing fabrics. Moisture influences the perceived comfort of the wearer as well as the amount of shrinkage during laundering, the rate of drying after laundering, and static electricity development" (Hyun, 1989, p. 28). Several factors determine how moisture will interact with a fabric, such as: fiber structure, fabric construction (whether it is woven or knit, along with the type of weave or knit used), and tpi (thread count per inch).

Watkins describes several ways in which water interacts with fibers. Water may be: 1) absorbed into the fiber so that it penetrates the surface and travels throughout the fiber structure, 2) adsorbed or held on the outer surface of the fiber, so that it does not penetrate through it, but is wicked or transported along the fiber surface, or 3) repelled by the fiber (1995). "Most textile fibers are hygroscopic; they have the ability to absorb or give up moisture" (Cohen, 1997, p. 35). All of the natural animal and cellulosic fibers are hydrophilic, as are regenerated fibers (fibers made from wood pulp). Cellulosic fibers (fibers made from cellulose, a naturally occurring polymer that forms the solid framework of plants) become stronger when wet. Although animal fibers are hydrophilic, their propensity for weakness when wet may render them less desirable for active wear. Manufactured fibers (man-made textile fibers produced by chemical synthesis) are normally hydrophobic; and yet, a number of them, such as olefin, possess good wicking action when microdenier in size (i.e., very thin filament fibers).

Manufactured fibers can be modified during the extrusion process, as well as through the application of a finish, to enhance or alter their properties and characteristics. "Polypropylene, a fiber that absorbs virtually no water, and is noted for its ability to wick, can be made into fabrics that hold a great deal of water. For this reason, polypropylene is often used in fabrics and garments that are planned to move sweat and insensible perspiration out of an ensemble" (Watkins, 1995, p. 30). Another example, Capilene ® polyester, a fiber created for cold-weather undergarments, is the result of a treatment grafted into the polyester fiber which attracts water to the fiber surface, spreading it out so that it moves from wetter areas of the fiber to drier ones and eventually dissipates, a form of wicking (Watkins, 1995).

Watkins notes that it is important to understand that the fiber is not the only dynamic that affects moisture transfer (1995). "Water passes through a fabric by capillary action (i.e., liquid being raised or depressed when in contact with a solid because of surface tension), or by the pressure of the water forcing it through the openings between the fibers, or by a combination of both methods" (Cohen, 1997, p. 111). The mechanisms by which fabrics are joined together often determine the mechanics of water transport (Watkins, 1995). Moisture is held by the fabric structure, within and/or between yarns. A weave or a knit has the potential to reduce or increase a fabric's ability to absorb water despite the fiber structure. A smooth surface (i.e., as found in both plain and satin weaves) reduces the wicking action. Fabric finishes can also be applied to woven or knitted fabrics to improve their performance properties. "The effectiveness of water repellents depends as much on fabric construction as on the repellent finish itself. To be effective repellents must be applied to tightly constructed fabrics" (Price & Cohen, 1997, p. 318). Fiber content, fiber configuration, fabric structure, and fabric finishes affect the insulative value of fabrics and the ability of the fabric to be waterproof/windproof, transfer moisture vapor, provide ventilation, and absorb heat.

Performance Fabrics

Many factors related to fiber content and fabric structure affect the design and performance of sport bras. Degree of stretch, thermal insulation, absorbency, wicking properties, drying rate, washability, and durability are a few of these factors. "The body, the environment, textile materials, and the clothing all work together to create a constantly changing thermal situation" (Watkins, 1984, p. 35). Designers of garments must take into account how each of these four complex conditions can affect each other and the performance of the intended product. Keeping cool, which is frequently associated with exercising, suggests wearing thinner open weave fabrics, loose fitting clothing, clothing that blocks radiant energy, and materials that keep excess moisture away from the skin surface.

Technological advances in structuring fibers have produced fabrics with specific features that make them good for athletic apparel, especially when sweating occurs. CoolMax® by DuPont, Hydrofil® by Allied-Signal, Inc., and DriRelease® by Optimer are all fabrics engineered to possess moisture management qualities.

"CoolMax® has propriety four-channel fibers" of Dacron polyester (CoolMax® Facts, 1999, p. 1). As the body perspires, the fiber channels move the moisture away from the skin to the outer layer of the fabric where it dries faster. DuPont claims that

CoolMax® has the fastest drying rate of any fabric and 3 times faster than cotton (CoolMax® Facts). CoolMax® fabrics are purported to be non-chafing, breathable, washable, dryable, and resist mildew, odors, and shrinkage. CoolMax® is frequently combined with Lycra®, also developed by DuPont, to add stretch to fabrics.

Hydrofil® nylon is the first commercially available absorbent nylon fiber (Hydrofil, 1988). A hydrophillic (water loving) nylon block co-polymer of nylon 6, does not rely on fiber shape or topical finish, but molecular configuration (True Fiber Technology, 1997). The *Total Moisture Management* system of Hydrofil® nylon includes four phases: wicking, drying, adsorption, and absorption (True Fiber Technology, 1997). Wicking of moisture through channels created by adjacent fibers and filaments move the water through the fabric rapidly for quick drying. This quick drying characteristic allows the fiber to manage more moisture. During adsorption, moisture and moisture vapor are held in the spaces between the fibers and filaments until wicking transports moisture to the fabric surface for evaporation. Moisture is attracted to the fiber molecules and pulled away from the surface of the skin by hydrophilic fibers. According to Allied-Signal's information brochure, Hydrofil® nylon can be used alone or combined with other synthetic or natural fibers to develop customized fabric systems that achieve these four phases of the *Total Moisture Management* system. Allied Signal, Inc. "push-pull" fabrics keep sweating skin dry by pulling the moisture into a raised hydrophobic (water hating) fiber next to the skin and pumping the moisture to the outer absorbent layer, Hydrofil®, where it spreads out and evaporates (Hydrofil®, 1988). Hydrofil® is machine washable and dryable, with stains, odors, and body oils washing out easily, and is not degraded by perspiration and moisture.

Optimer's scientists used their knowledge of molecular science to develop Dri-Release™, a unique microblend of cotton and polyester. Dri-Release™ utilizes the best qualities of cotton and polyester to pull moisture from the body and disperse it into the environment (Dri-Release™, 1999). Cellulosics are long chains of hydroxyls (OHs), which form hydrogen bonds with the OHs in water. By bonding with the perspiration, the cotton fibers absorb the moisture. Then the polyester fiber forces the moisture through to the surface of the garment.

Spandex® is a generic fiber that stretches more than 500%, has excellent recovery, and only requires a small percentage of it to achieve stretch (Brown and Rice, 1998). Although spandex is weak, it is resistant to sun and chemicals such as perspiration and chlorine and will withstand rigorous care in the washing machine. Lycra® by DuPont is a well-known spandex fiber with limitless possibilities.

Standard Classification

In 1982, the American Society for Testing and Materials (ASTM) Committee F-8 on Sports Equipment and Facilities established a standard for the classification of brassieres or undergarments worn in direct contact with the breast for the purpose of protecting or supporting breast tissue in athletics, sports, or other physical activities (ASTM, 1990). Subcommittee FO8.93 on Female Athletes developed the standard to define and classify both supportive and protective sport bras to assist consumers, manufacturers, and researchers of brassieres. Supportive brassieres are defined as "those intended to constrain the breasts, that is, to limit the displacement of breast tissue during physical activity. All brassieres intended for use in physical activity must meet this description" (ASTM, 1990, p. 342). Protective brassieres are defined as "those intended to provide safety from external objects impacting the breasts" (ASTM, 1990, p. 342). The ATSM is continuing to formulate test methods and specifications, however, little has been done to help physically active women select and evaluate bras based on ASTM criteria.

CHAPTER III

METHODOLOGY

This chapter describes the sample, independent variables, dependent variables, equipment, data collection protocol, and overall procedures used for evaluating the effectiveness and subjects' perceptions of comfort and support of a prototype sport bra and two commercially available sport bras, and the statistical analyses.

Sample

A convenience sample, consisting of six physically active females, who passed a physical screening procedure, and a prescreening for fit of the garment treatments, constituted the volunteer subjects of the study. Participants were approximately the same bust size, with brassiere sizes being limited to: 32DD, 34D/DD, or 36C/D. Participants were members of a fitness center or exercise class and were between the ages of 23 and 37. They were solicited from fitness centers located locally or on campus through the posting of a flyer (Appendix A).

When potential subjects inquired about participating in the study, an initial meeting with the researcher was scheduled. The purpose and nature of the experiment was explained during this initial meeting to acquaint the potential subjects with the study's requirements. Each participant was given a "Subjects' Information Card" (Appendix B) and asked to complete this form to obtain basic demographic, physical, and exercise information, along with their schedules and local telephone numbers. Interested subjects were screened through physical measurement by the researcher to determine their appropriate brassiere size. Potential subjects were eliminated from further consideration if they did not fall within the specified size range, had breast augmentation surgery, indicated they were pregnant, or indicated their inability to jog on a treadmill. Two potential subjects were eliminated from participating in this study due to health problems. Those who completed the "Subjects' Information Card" satisfactorily, met the sizing criteria, and were willing to participate in the research study were asked to sign the "Subjects' Consent Form" (Appendix C). Personnel at the Oklahoma State University Wellness Center screened the personal information gathered for subjects with potential health problems. Subjects, who passed the screening process described below, participated in and completed the research protocol, including the biomechanical and the thermal testing components. Upon completion of the study, subjects kept the three garment treatments that they had worn during the study.

Physical Screening Process

The physical screening procedure consisted of sequential processes such that if a volunteer did not pass a test, the physical screening process was terminated and the volunteer was thanked for their interest in the study and excused. The three forms included: (1) an adapted form of the Physical Activity Readiness Questionnaire (PAR-Q test), (2) a Pattern of Exercise Questionnaire, and (3) a medical history analysis. The PAR-Q test (Appendix D) was used to identify potential health problems of subjects who should not participate in the physical activity of the test. If a potential subject responded, "yes" to any question, they were eliminated from further consideration. Part II: Pattern of Exercise (Appendix D) was developed by the researcher to obtain information from subjects regarding their exercise habits. Potential subjects that indicated they had not maintained a regular aerobic exercise regime over the past several months were eliminated from further consideration.

Upon successful completion of the first two forms, subjects completed the medical history analysis (Appendix E). A staff member from the OSU Wellness Center reviewed the medical history analysis for each individual to determine whether the volunteer should participate in the study. Once accepted, the subjects were scheduled for test sessions and provided directions regarding clothing and testing procedures.

Approval for all experimental procedures was obtained from the Oklahoma State University Institutional Review Board (IRB) for human subjects before the experiment (Appendix F).

Independent Variable

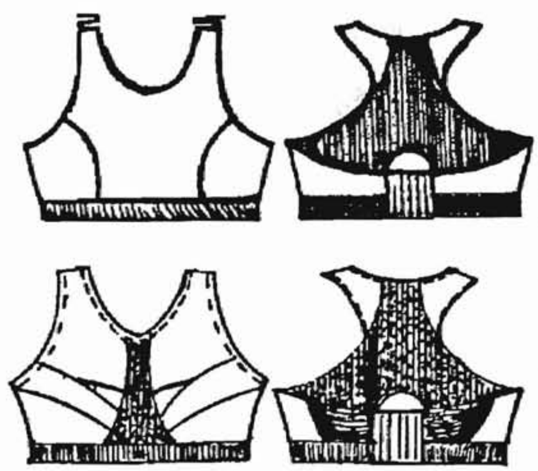
Garment treatment was the independent variable with three different levels. Three garment treatments, garments A, B, and C, were worn in the testing procedures. The researcher provided each participant with a personal set of, black and white, garment treatments. Each garment treatment was laundered in cold water, delicate cycle, and line dried before and after each test session. Participants provided and wore the same pair of running shorts, socks, and athletic shoes for each test session.

Garment A - Prototype Sport Bra Development

Grace Krenzer and the researcher designed garment A, the prototype sport bra, using the functional design process delineated in Watkins (1995) as a part of a graduate course in functional design. Literature review revealed characteristics that a good sport bra should possess. A survey instrument evaluated users' perceptions of fit and performance of sport bras, determined users' design preferences, and provided insight into the complex engineering problem involved in designing performance sport bras. Textile testing of multiple candidate materials, using standard ASTM and AATCC test methods, narrowed the selection of the prototype's fabrics.

Design and materials specifications and design criteria were developed and ranked. The resulting prototype sport bra was designed to resolve specific comfort, support, and aesthetic issues reported by large-busted women. This was accomplished through fabric choices, design modifications, and fabric layering.

The prototype sport bra consists of an inner and an outer bra (Figure 1). Fabrics for the bra were selected based on the results from four textile laboratory tests, specifically: dimensional stability (AATCC Test Method 96-1972), pilling (ASTM D3512-97), abrasion resistance (ASTM D3888-809), and wicking tests (Harnett and Metha, 1984). A 68% polyester and 32% Lycra CoolMax® fabric with 2-way stretch, that performed better in the dimensional stability and pilling tests than the other candidate fabrics, was used as the outer fabric. A brushed non-stretch knit, polyester and Hydrofil® nylon fabric with good wicking and dimensional stability results, was used for the interior fabric to form a stabilizing foundation.



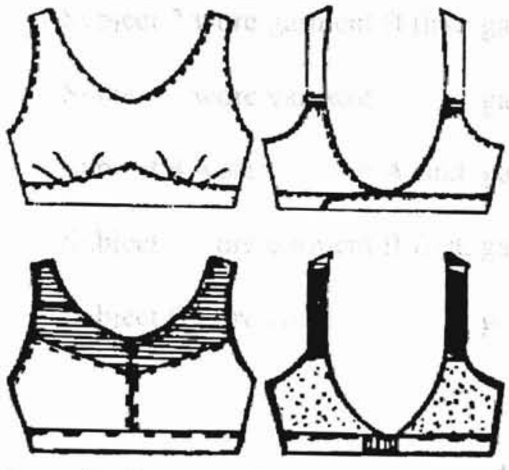
Exterior Bra:	**Front View:** Shoulder Strap Adjustment 1½" Wide Band **Back View** Mesh Insert: Single Layer Key-hole Opening 1½" Wide Back Clasp
Inner Bra:	**Front View** Non-stretch Molded Cups **Back View** Mesh Insert: Single Layer Non-stretch Shoulder Straps Wings: Double layer of self-

Figure 1. Garment Treatment A

The prototype combined an encapsulating inner bra with a compression styled outer bra in order to lift and support the breast tissue. It was hypothesized that the inner bra would help minimize breast displacement through its ability to separate and contain each individual breast. The straps are lined with woven, non-stretch Hydrofil® nylon fabric to prevent stretching, a feature designed to increase support. Other design features incorporated into the prototype sport bra include: racer-back styling for easy movement; wide, non-slip shoulder straps for better distribution of weight; a 1 ½" band of elastic around the ribs for support and reduction of ride up; a back closure with a key-hole opening for ease of donning and doffing; and adjustable shoulder straps and back band for improved fit.

Garment B

Garment B combines an encapsulating inner bra with a compression style outer bra in order to lift and support the breast tissue (Figure 2). The inner bra is constructed of a non-stretch fabric of 56% cotton and 44% polyester and is advertised as having a hidden support panel that is purported to limit breast movement. The outer fabric consists of 43% cotton, 43% polyester, and 14% Lycra® spandex. An adjustable back closure and non-slip straps with Velcro® strips are additional features.

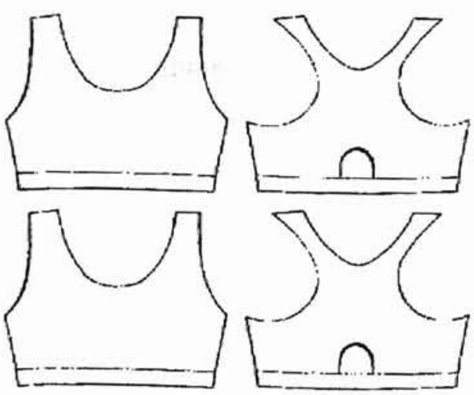


Exterior Bra: **Front View:**
Band covered with self-fabric
Back View
Shoulder Strap Adjustment
1 " Wide Back Clasp
Inner Bra: **Front View**
Non-stretch Molded Cups
Straps lined w/Non-stretch
fabric
1 " Wide Back Clasp
Back View
Elastic Shoulder Straps
Hook & Loop Tape Shoulder

Figure 2. Garment Treatment B

Garment C

Garment C is a pull-on compression style sport bra constructed of 95% cotton and 5% Lycra® spandex (Figure 3). The racer-back styled sport bra is lined with 100% CoolMax® polyester and has wide straps.



Exterior Bra: **Front View:**
1" Wide Band
Back View
Key-hole Opening

Inner Bra: **Fully-lined Front & Back**

Figure 3. Garment Treatment C

Experimental Design

The study used a repeated measures design. For the three garment treatments, there were six possible distinct order combinations for wearing the three garments based on a Latin Square counter balancing scheme. Each volunteer subject was randomly assigned to one of the following six presentation orders of wearing each garment:

Subject 1 wore garment A first, garment B second, and garment C last, Subject 2 wore garment B first, garment C second, and garment A last,

Subject 3 wore garment C first, garment A second, and garment B last,

Subject 4 wore garment A first, garment B second, and garment C last,

Subject 5 wore garment B first, garment C second, and garment A last,

Subject 6 wore garment C first, garment A second, and garment B last.

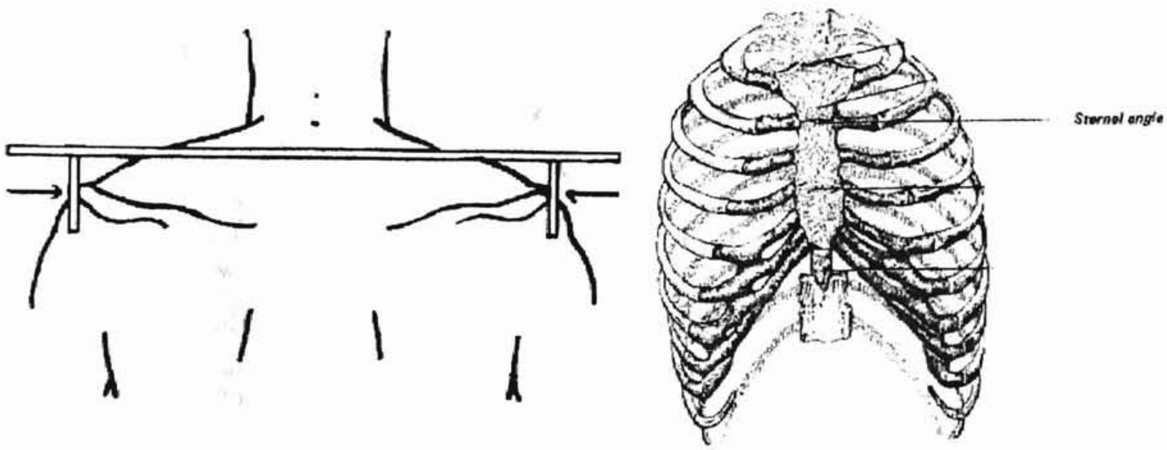
Three separate test sessions were scheduled and subjects were required to wear the assigned treatment to each session. Each test session was conducted in the environmental chamber, which was set at an ambient temperature of 75° F ± 1° and 40% RH ± 5%.

Dependent Variables

Dependent variables consisted of: sweat rate (SR)) at one location, heart rate (HR), one local skin temperature (ST), vertical breast displacement, and the effective measures of thermal sensation, thermal comfort, moisture and other garment characteristics. Pre- and post-weights of the garment treatments were also taken to determine absorption of moisture.

A video-based motion analysis system was used to measure vertical breast displacement. Styrofoam balls covered with reflective tape served as reflective markers, while a scaling rod with four feet indicated by reflective tape served as a reference measurement tool before each exercise protocol. Reflective markers placed on the Lateral points of Acromion Processes (Figure 4) provided a perpendicular reference line. Reflective markers placed on the Sternal Angle (Figure 4) of the sternum measured vertical displacement of the body. Reflective markers were placed on the surface of the sport bra at each bust point (Figure 5) to measure vertical motion of the breast. Videotapes recorded the motion of the reflective markers during each test session.

Marker positions analyzed frame-by-frame and combined with calibration determined the three-dimensional coordinates. The total amount of vertical breast displacement during each step was determined by finding the difference between the maximum and minimum vertical positions of each breast.



Lateral points of Acromion Processes (Croney, 1971, p. 55)

Sternal Angle (Hay & Reid, 1982, p. 62)

Figure 4. Physical Landmarks

Pre- and post-weights of the garment treatments (placed in the same re-sealable plastic bag) before and after each test session were recorded. Skin temperature was monitored and recorded every minute using a data logger system connected to a personal computer. One skin thermocouple (Figure 5) was secured to each subject's skin with athletic tape on the upper chest under the garment treatment. A dew point capsule (Figure 5) was taped in close proximity to the skin thermocouple on the upper chest under the garment treatment. Dew point was measured using a dew point hygrometer system connected to a personal computer that converted dew point to sweat rate. Data were collected and recorded at one-minute intervals.

Heart rate was determined every minute using a Polar Accurex II heart rate transmitter and monitor. Each subject wore the transmitter around her chest and the monitor on her wrist. The monitor automatically recorded the heart rate information; the researcher downloaded heart rate data using software purchased with the heart rate monitor.

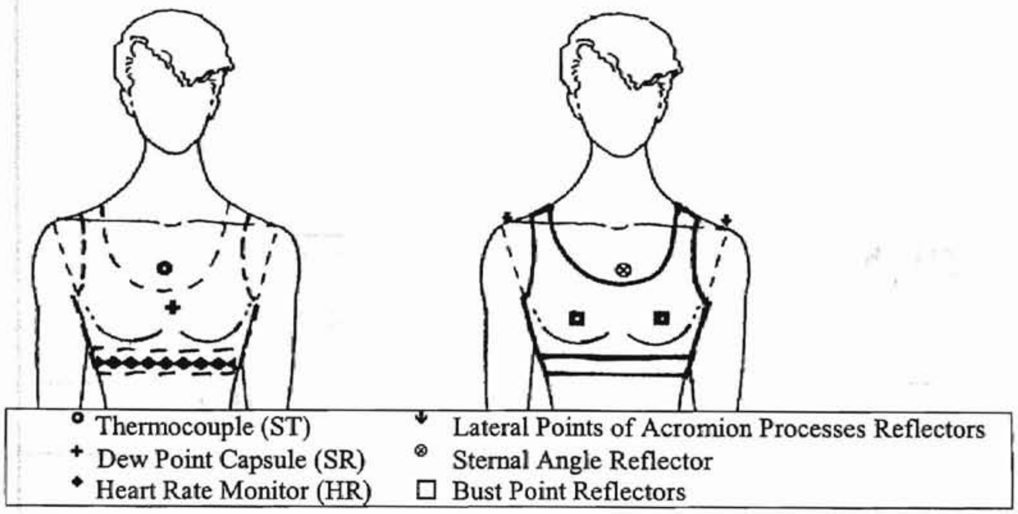


Figure 5. Instrumentation Placement

Hollies' Subjective Rating Scale Ballot was modified for this study in the following ways: the original 11 were increased to 12 comfort descriptors, definitions of each comfort descriptor was added, and the original 4-point response scale was converted to a 5-point response scale. Stiff, static, sticky, nonabsorbent, cold, damp, picky, rough, and scratchy were replaced with absorbent, breathable confining, dry, hot itchy, smooth, soft, warm, and wet. Clammy and clingy were the only comfort descriptors not changed. Every five minutes, subjects were asked to subjectively evaluate the garment treatment they were wearing by rating the intensity of 12 descriptors when prompted by the investigator. An enlarged Comfort Descriptor Rating Ballot (Figure 6) was posted directly in front of the subjects during the testing, and the researcher recorded subjects' responses on the subject's individual ballot.

COMFORT DESCRIPTOR RATING BALLOT					
DATE		GARMENT			
SUBJECT					
	Intensity Scale 0 (Not at all) 1 (Partially) 2 (Mildly) 3 (Definitely) 4 (Totally)				
COMFORT DESCRIPTORS		RATING PERIOD			
		1	2	3	4
ABSORBENT:	able to absorb moisture				
BREATHABLE:	allowing air to pass through				
CLAMMY:	being damp				
CLINGY:	adhering to skin				
CONFINING:	hindering movement				
DRY:	being dry				
HOT:	being hot				
ITCHY:	irritating to skin				
SMOOTH:	a continuous even surface				
SOFT:	pleasing to touch				
WARM:	the feeling of being warm				
WET:	the feeling of being wet				

Hollies' Subjective Rating Scale (1977)

Figure 6. Modified Comfort Descriptor Rating Ballot

Test Protocol

Trial Procedure

Trial procedures identified faulty equipment and potential protocol discrepancies. The researcher corrected protocol discrepancies and replaced faulty equipment. A second trial procedure tested new equipment and corrected the research protocol.

Test

Prior to each subject's arrival, the garment treatment was weighed in a plastic, re-sealable bag on a top-loading digital readout balance to the nearest hundredth gram. Upon arrival for each subject's first visit to the Environmental Design Laboratory, located in the College of Human Environmental Sciences, the researcher reviewed the study protocol and gave each a brief tour of the environmental chamber. Black felt was hung on the chamber walls directly behind and to the side of the treadmill to serve as a non-reflective, backdrop for the videotape. All necessary charts were hung on the chamber wall directly in front of the treadmill and within easy view. The researcher introduced the perception ballot to the subjects and allowed them to familiarize themselves with the ballot and its terminology. Placement of the reflective markers, and the skin temperature, heart rate, and sweat rate instruments was demonstrated to the subjects. The testing protocol consisting of three phases: acclimation, exercise, and rest/recovery, as well as the videotaping procedure was explained to the subjects. Subjects reviewed the treadmill protocol and familiarized themselves with the treadmill. Each subject then donned the standardized clothing ensemble with the unidentified assigned garment treatment. For subsequent test sessions, the tour and review were eliminated.

The 30-minute test session consisted of a 10-minute acclimation phase, 15-minute exercise phase and a 5-minute rest/recovery phase. The acclimation phase began immediately after each subject dressed and entered the chamber. During this ten minute phase, the subjects were standing. All surface skin sensors were attached to the designated body sites with medical tape under the garment treatment. The heart rate transmitter was strapped around the subject's rib cage, just below the bra band and the monitor was strapped around the wrist, like a watch. Once all other instruments were in place, the five reflective markers were attached to the designated body sites (see Figure 5) with double-stick tape. After instrumentation, subjects stood on the treadmill in the location that they would normally run. A spotlight was directed toward the reflective markers for effective videotaping. A sample comfort ballot was administered and completed during this phase. The researcher posted an enlarged list of descriptor terms and intensity ratings from the comfort ballot directly in front of the subjects for easy reference.

A super VHS video recorder was set up in the Environmental Design Laboratory and lined up directly with the subject for each videotaping segment of the study. A Peak Motus® Motion Measurement System captured and analyzed the motion data, frame-by-frame. Each videotaping segment was minimal as only the first three running strides were recorded.

The 15-minute exercise phase began with a fast walk for three minutes. This was followed by an increase to a 5 mph jog on a flat grade for ten minutes, then gradually reduced to a slow walk over a two minute time period. This physical activity was determined to be rigorous enough to induce sweating.

Throughout the exercise protocol, subjects were asked every five minutes to subjectively evaluate the garment treatment they were wearing. Subjects rated the intensity using 12 tactile descriptors, wetness sensation, thermal comfort, and overall clothing comfort when prompted by the investigator. The researcher recorded the comfort ballot using the subject's responses on their comfort ballot.

The 5-minute rest/recovery phase consisted of a slow walk, allowing the subjects to cool down and the heart rate to reduce to normal. At the conclusion of this phase, the researcher removed all instrumentation and gave the subject a bottle of water. Then the subject and the researcher left the environmental chamber. The subject changed into her street clothes and gave the unidentified garment treatment to the researcher. The unidentified garment treatment was sealed in the same plastic bag and weighed on the same top-loading digital readout balance to the nearest hundredth gram. The researcher confirmed the scheduling of the next session.

Early Termination

If any of the following criteria occurred, the experiment was to be terminated:

1. A subject's heart rate rose above 220 beats per minute,
2. A subject felt that she could not continue despite verbal encouragement,
3. A subject's heart rate monitor sounded an alarm, and
4. If at any time, a subject was not able to verbally respond.

The researcher adhered to and posted these guidelines on the chamber wall. The researcher closely monitored each subject for changes in behavior and the ability to verbally respond to questions. None of the above mentioned criteria occurred, necessitating the early termination of an exercise session.

Statistical Analyses

The mean data were graphed for the following dependent measures: skin temperature, sweat rate, heart rate, and perceived thermal comfort. The total amount of vertical breast displacement was calculated, as well as the mean difference of six vertical displacement values, three rises and falls of each breast was graphed. ANOVA was used to investigate for garment differences in skin temperature, sweat rate, heart rate, garment weight gain, perceived thermal comfort, and vertical breast displacement. When a significant difference was found a post-hoc procedure was done.

CHAPTER IV

MANUSCRIPT 1

BIOMECHANICAL AND THERMAL COMFORT ANALYSES OF A PROTOTYPE SPORTS BRA

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Abstract

Despite increased emphasis on exercise for improved health and well being, many large-busted women refrain from exercising due to breast pain and discomfort. A recent survey found that large-busted respondents reported being unable to find well-fitting, comfortable, supportive sports bras (Starr & Krenzer, 2000). The purpose of this study was to compare a prototype sports bra previously developed for large-busted women using a systematic design process, with two commercially available sports bras through a controlled laboratory wear study under selected environmental conditions of 75° F ± 1° F and 40% RH ± 5%. The prototype sports bra was designed to improve support and thermal comfort using a combination of design features and materials selected. The overall project used two methods, one to assess support and one to assess thermal comfort.

Six physically active females between the ages of 23 and 37 (mean age 34 years) were recruited from a university fitness center. All subjects were approximately the same bust size (32DD, 34D/DD, and/or 36C/D), passed the physical screening process, and were assumed to be capable of performing maximal physical output. Subjects were allowed to keep all three sports bras at the conclusion of the test sessions. The garment treatments consisted of garment A, a prototype sports bra with both compression and encapsulation characteristics; garment B, a commercially available sports bra with compression and encapsulation characteristics; and garment C, a commercially available compression sports bra. Subjects performed a 30-minute exercise routine on a treadmill, consisting of warm-up, jogging, and cool down phases. The following dependent variables were measured at 1-minute intervals over the length of the test session: sweat

rate, heart rate, and skin temperature. Perceptions of thermal sensation, thermal comfort, moisture and other garment characteristics were assessed by using a modified version of Hollies' (1977) subjective comfort ballot at five minute intervals over the length of the test. Pre- and post-weights of the garment treatments were taken and vertical displacement of the breast was measured during the first three strides while jogging.

A Repeated Measures Design with a Latin Square balancing scheme was used to minimize potential bias resulting from the order in which garments were tested. All six subjects wore each of the test garments in three separate, 30-minute test sessions. The protocol consisted of the following: a 10-minute acclimation phase, where the subjects were instrumented in the environmental chamber, followed by a 15-minute exercise phase with a 5-minute cool down. The 15-minute exercise phase began with a 3-minute fast walk, followed by a 10-minute jog at 5 mph on a flat grade, and ended with a gradual reduction in speed over two minutes. The test session culminated with a five minute slow walk as the rest/recovery phase. All instruments were removed and each subject was offered a sports drink and/or a bottle of water.

The ANOVA indicated a significant difference in skin temperature and sweat rate over time, and a significant difference in heart rate by garment and time. LSD tests showed there was a significant difference in pre- and post- for garment weight, with garment A having the greatest weight gain. The perceptual data indicated a significant difference by time for eleven descriptors, a significant garment-by-time effect for wetness, and a significant garment effect for dry, thus partially supporting the physical data. ANOVA results of the movement data found significant subject, garment, and subject-by-garment effects, with garment A and B providing the most support.

Introduction

With passage of the Title IX legislation in 1972, there was a dramatic increase in the number of women participating in sports and regular strenuous exercise. This increase was due to legislation mandating equal sports opportunities for girls and women. The increase may also be attributed to an increasing number of women employed in physically challenging careers.

In a September 17, 1998 news release, the American Council on Exercise (ACE) reported a majority of women experience breast discomfort while exercising, causing some to avoid exercise all together (1998). Physical activity causes the breasts to bounce. As the activity increases, so does the bounce and the larger the breasts, the greater the vulnerability. Skin and ligaments (elastic connective tissue) provide a fragile support structure for the breasts that can be compromised by too much bouncing and stretching, and sagging can result (Stamford, 1996). Greater emphasis is being placed on fitness, a positive self-image, and personal enjoyment, rather than focusing primarily on weight loss. The Surgeon General states that physical activity joins the front ranks of essential health objectives, such as sound nutrition, use of seat belts, and prevention of adverse health effects of tobacco (U.S. Department of Health and Human Services, 1996). He concludes that it behooves us, as Americans, to promote exercise in our own unique way. Controlling breast movement during exercise is one important factor to consider in the effort to encourage and promote women's participation in exercise activities.

Sports underwear has gained more visibility of late, both figuratively and literally. "When Brandi Chastain scored the winning shot in a tense, overtime shootout with China in the World Cup soccer final, she did more than just shed her shirt to celebrate the team's triumph. She fired the hopes of sports bra makers everywhere." (Segal, 1999, July 15, p. E01). In that moment of exuberance, Brandi revealed the black Nike sports bra that she had assisted designers in designing. This virtual unveiling brought instant attention and fame to a sturdy undergarment. "The sports bra is the cloth symbol of Title IX's success" (Gerhart, 1999, July 14, p. C01). Ann Gerhart of The Washington Post claims that $230 million worth of sports bras were sold in 1998, up from $205 million the year before.

There are two basic designs of sports bras: compression and encapsulation. The former flattens breasts to redistribute their mass evenly across the chest; the latter supports each breast separately in its own cup (similar to conventional bras). The design engineering of bras must defy laws of gravity and bras are often compared to suspension bridges with support coming from four directions: straps, band, circumference, and two intersecting 180 degree arcs of the cups (Nanas, 1964). To design a bra that accomplishes this engineering feat and is comfortable to wear requires a designer with expertise and a high level of heuristic knowledge, with heuristic knowledge being problem-solving techniques that utilize self-educating techniques (Hardaker & Fozzard, 1997).

Existing research on breast motion and the desirability of specially designed sports bras confirmed the need for firm breast support, particularly among large-breasted women (Gehlsen & Albohm, 1980; Haycock, 1978; Hunter & Torgan, 1982; Lorentzen & Lawson, 1987; Schuster, 1979). The consensus of these studies suggests that different cup size groups may require different support and design requirements and that the current industry practice of designing bras for various cup sizes in exactly the same way is unacceptable. This poses a real design challenge for the sports bra designer and presents a viable vehicle to improve the health of the nation by affirming our commitment to healthy physical activity on all levels: personal, family, community, organizational, and national.

Purpose

The purpose of this study was to compare a prototype sports bra previously developed for large-busted women using a systematic design process, with two commercially available sports bras through a controlled laboratory wear study under selected environmental conditions. The prototype sports bra was designed to improve support and thermal comfort using a combination of design features and selected materials. Specifically, the objectives were to determine 1) subjects' skin temperature and sweat rate at a selected location, and heart rate during a specific exercise protocol while wearing each garment treatment, and to compare the findings by garment treatment, over time, 2) the subjects' perception of comfort and support during a specific exercise protocol while wearing each garment treatment, and to compare the findings by garment treatment, over time, 3) the amount of breast displacement during a specific exercise protocol while wearing each garment treatment, and to compare the findings by garment, and finally, to compare 4) the subjects' perception of comfort and support with the physical and physiological data gathered during the exercise protocols.

Prototype Development

The team of Starr and Krenzer (2000) developed a prototype sports bra using the functional design process delineated in Watkins (1995) as a part of a graduate course in functional design. The literature review indicated characteristics that a good sports bra should possess. A survey instrument determined users' perception of fit and performance of sports bras, users' design preferences, and insight into the complex engineering problem involved in designing performance sports bras. Multiple candidate materials were tested using standard ASTM and AATCC test methods to select the prototype's fabrics. Design and materials specifications and design criteria were developed and ranked. The resulting prototype sports bra was designed to resolve specific comfort, support, and aesthetic issues reported by large-busted women. This was accomplished through fabric choices, design modifications, and fabric layering.

Methods and Procedures

Subjects

Six physically active females between the ages of 23 and 37 (mean age 34 years) were recruited. All subjects were approximately the same bust size (32DD, 34D/DD, or 36C/D), passed the physical screening process, and were assumed to be capable of performing maximal physical output. The nature of the experiment was explained to the subjects, and those volunteers who met the criteria for the experience were asked to sign an informed consent form.

Independent Variable

Three garment treatments were used in the test sessions: garment A (see Figure 1, p. 34), the prototype sports bra with both compression and encapsulation characteristics; garment B (see Figure 2, p. 35), a commercially available sports bra with compression and encapsulation characteristics, and garment C (see Figure 3, p. 36), a commercially available compression sports bra.

Table 1 provides physical characteristics that describe the fabrication and pre-test weight of all three garment treatments. While fabrication was different for all three, each incorporated a moisture moving mechanism of some fashion. Garment A incorporated CoolMax™ polyester in the two exterior fabrics, while the inner bra incorporated a brushed Hydrofil® nylon. CoolMax™ polyester is a four-channel fiber engineered to wick moisture along the channels, while Hydrofil® nylon is an absorbent nylon engineered to wick, dry, adsorb, and absorb (see Chapter II, p.28). Garment B incorporated CoolMax™ polyester within it's two layers of fabrication, while garment C incorporated CoolMax™ polyester in the lining. All three garment treatments were weighed prior to each exercise protocol. Garment A weighed the most at 139 grams, Garment B was the second highest at 105 grams, and Garment C weighed the least at 55 grams.

Table 1. Garment Fabrication

	Garment A		Garment B		Garment C	
	Exterior Bra Fabric	Inner Bra Fabric	Exterior Bra Fabric	Inner Bra Fabric	Exterior Bra Fabric	Lining Fabric
Fiber Content	Front & Straps: 68% Coolmax®/ 32% Lycra® Back Insert: 72% Coolmax®/ 28% Lycra®	Polyester/ Hydrofil® w/Brushed Finish	43% Cotton/ 43% Poly/ 14% Lycra®	Front & Straps: 60% Poly/ 40% Cotton Wing: 86% Nylon/ 14% Lycra®	95% Cotton/ 5% Lycra®	100% Coolmax®
Construction	Double Filling Knit (Interlock); Mesh Insert	Warp Knit (Tricot)	Double Filling Rib Knit	Warp Knit (Tricot); Mesh Wing	Single Filling Knit (Jersey)	Single Filling Rib Knit
Pre-test Garment Weight	139.26 grams		105 grams		55 grams	

Physical characteristics that describe the style and unique design features of all three garment treatments are included in Table 2. While design features were different for all three, each incorporated a support mechanism of some fashion. The foundation of both Garment A and B's support system is the full inner support bra that encapsulates each breast individually, the only difference being that Garment A's inner bra is constructed of non-stretch fabric. Along with the inner support bra, Garment A supports the breasts with an outer support bra that compresses the breast tissue to the chest cavity and non-stretch, racer-back style shoulder straps. Along with the inner support bra, Garment B supports the breasts with an outer support bra that compresses the breast tissue to the chest cavity and stretchable, over-the-shoulder style bra straps. Garment C's support system relies on racer-back style shoulder straps and compression.

Table 2. Garment Style and Fit Features

	Garment A	Garment B	Garment C
Garment Style	Compression/ Encapsulation	Compression/Encapsulation	Compression
Moisture Management	CoolMax™ polyester rib band, exterior bra of CoolMax™ polyester and inner bra of Hydrofil® nylon	CoolMax™ polyester rib band, exterior and inner bra of CoolMax™ polyester	CoolMax™ polyester lining
Secure Breast Motion Control	Non-stretch inner bra w/molded cups, non-stretch racer-back straps, and pull-over compression	Full inner bra with molded cups	Racer-back straps and pull-over compression
Adjustability	Back clasp, adjustable shoulder straps, and a back key-hole opening (expansion joint)	Back clasp and adjustable shoulder straps	Back key-hole opening (expansion joint)
Breathability	Back mesh insert and key-hole opening (expansion joint)	Thin shoulder straps and small back clasp	Back key-hole opening (expansion joint)
Comfort	Wide, racer-back (non-slip) shoulder straps, wide bra band, plush-lined hardware, and inner bra of brushed, satiny-soft nylon/spandex with cover stitched seams to prevent chafing	Plush-lined hardware	No hardware or seams to chafe

Dependent Variables

The following dependent variables were measured at 1-minute intervals over the length of the test session: sweat rate at one location, heart rate, and one local skin temperature, as shown in Figure 5 (Chapter III, p. 38). Sweat rate was measured by a dew point hygrometer system using a dew point capsule, skin temperature was measured by a data logger system using a thermocouple, and heart rate was measured by using a Polar Accurex II heart rate transmitter. All physiological sensors were taped, under each garment treatment, directly to the subject's skin using surgical tape. Once the physiological sensors were in place, reflective markers were taped on the following anatomical landmarks: Lateral points of Acromion Processes, Sternal Angle, and both bust points, as shown in Figure 5 (Chapter III, p. 38). Videotape recorded the breast displacement data, one frame at a time, during the first three running steps of each test session.

A modified version of Hollies' subjective comfort ballot (1977) taken at 5-minute intervals over the length of the test was used to assess perceptions of thermal sensation, thermal comfort, moisture and other garment characteristics. The original comfort ballot consisted of 11 comfort descriptor terms and a 4-point response scale, (1977), for measuring perceived comfort intensity of a given sensation. For this study, 12 descriptors were identified and given short definitions for clarification (Figure 6, p. 39). Subjects were asked to rank the intensity of the 12 comfort characteristics on a 5-point response scale of zero (not at all) to four (totally) the overall comfort of the prototype garment. Pre- and post-weights of the garment treatments were taken.

Testing Protocol

Prior to each subject's arrival, the garment treatment was weighed in a plastic, re-sealable bag on a top-loading digital readout balance to the nearest hundredth gram. The environmental chamber was draped in black felt as a backdrop for videotaping, and the environmental conditions were determined to be holding steady at 75° F ± 1° and 40% RH ± 5%. All necessary charts were posted on the chamber wall directly in front of the treadmill and in the changing area provided.

Upon arrival for the first test session at the Environmental Design Laboratory, each subject was given an introductory session to review the study protocol and all instruments. The researcher introduced the perception ballot to the subjects to familiarize them with the ballot and terminology. Placement of the reflective markers, and the skin temperature, heart rate, and sweat rate instruments was shown to the subjects. The testing protocol, consisting of three phases: acclimation, exercise, and rest/recovery, as well as the videotaping procedure, was explained to the subjects. The treadmill protocol was reviewed. Each subject then donned the standardized clothing ensemble with the unidentified assigned garment treatment.

After dressing, the subjects entered the chamber and the acclimation phase began. This phase of the protocol lasted approximately ten minutes, during which time the subject stood at ease and was instrumented as indicated in Figure 5, (Chapter III, p. 38). All surface skin sensors were attached to the designated body sites with medical tape under the garment treatment. The heart rate transmitter was strapped around the subject's rib cage, just below the bra band, and the monitor was worn on the wrist. Once all of these instruments were in place, the five reflective markers were attached to the designated body sites using a combination of medical tape and double-stick tape. Placement of the five reflective markers was determined by palpating the shoulder area to locate the Lateral points of Acromion Processes and by palpating the sternum area to locate the Sternal angle. Each subject determined bust point placement and placed the reflectors on both bust points.

After instrumentation, each subject was asked to stand on the treadmill in the location that she would normally use for running and to become accustomed to the treadmill. A spotlight was adjusted during this time to shine directly on the reflective markers and not in the subjects' eyes for effective videotaping. A sample comfort ballot was also completed during this phase. An enlarged list of descriptor terms and intensity ratings for the comfort ballot was posted directly in front of the subjects during the entire exercise protocol for easy reference.

A super VHS video recorder was set up in the Environmental Design Laboratory and lined up directly with the subject for the videotaping segment of the study. Motion and data were analyzed, frame-by-frame, using a Peak Motus® Motion Measurement System. Once the first three running strides were taped, the video recorder and the spot light were turned off and the test session continued.

The fifteen minute exercise phase began with a fast walk for three minutes, followed by an increase to a 5 mph jog on a flat grade for ten minutes, and lastly, a gradual reduction in speed over a two minute period. This physical activity was rigorous enough to induce sweating.

Throughout the exercise protocol, subjects were asked every five minutes to subjectively evaluate the garment treatment they were wearing by verbally rating their perception of the intensity of all 12 comfort descriptors, wetness sensation, tactile sensation, thermal comfort, and overall clothing comfort when prompted by the investigator. The researcher completed the comfort ballot according to their responses, as they were either walking or jogging depending on where they were in the protocol.

The rest/recovery phase followed the exercise phase and consisted of a slow walk, which lasted approximately five minutes. All instrumentation was removed at the end of the five minute rest/recovery phase, if the subject's heart rate returned to within a normal range, and offered a sports drink and/or a bottle of water. However, one subject's heart rate had not returned to a normal range, so the heart rate monitor was left in place until the heart rate fell within an acceptable range. At the end of this phase, the subject was offered a sports drink and/or a bottle of water.

At the conclusion of this rest/recovery phase, the subject and the researcher left the environmental chamber. The subject changed back into her street clothes and gave the unidentified garment treatment to the researcher. The unidentified garment treatment was placed in the same plastic, re-sealable bag and weighed on the same top-loading digital readout balance to the nearest hundredth gram. The researcher confirmed the scheduling of the next session with the subject.

Results and Discussion

Analysis of variance tests were used to determine if there were significant differences by subject, garment, time, garment-across-time, and garment-by-subject interaction. There was no garment-by-time interaction for any of the three response variables: heart rate, skin temperature, or sweat rate. There was significant garment and time effect for two dependent variables, which were heart rate and the comfort descriptor dry. There was a significant time effect and garment-over-time interaction for the moisture sensation of wetness. There was only significant time effect for skin temperature, sweat rate, and 10 of the 12 comfort descriptors, which included: absorbent, breathable, clammy, clingy, confining, dry, hot, smooth, soft, and warm. There was significant subject, garment, and subject x garment interaction for vertical breast displacement. Differences of Least Squares Means were used to distinguish differences by garment.

Heart Rate

During the first three minutes, subjects walked and their heart rate gradually increased. For the next 10 minutes, subjects jogged at 5 mph and their heart rate gradually increased. Correspondingly, when the subjects' speed was reduced to 3 mph, their heart rates began to drop. Figure 7 shows mean heart rate data for all garment treatments. There was a general tendency for heart rate to increase over the first twelve minutes, level off for the next several minutes, and then to rapidly drop off as the speed is reduced. The increase and decrease in heart rate appears to coincide with the exercise protocol and the resulting expenditure of energy.

Subjects wearing garment C had consistently higher mean heart rate readings during the first thirteen minutes, followed by a brief leveling and a rapid drop. Subjects wearing garment B experienced the lowest heart rate readings during the first six minutes, then they experienced similar readings as subjects wearing garments A and C. Subjects in garment A experienced initial heart rates between the rates for garments B and C, and then similar rates followed by a decline. However, this decline was higher than the decline for subjects wearing garments B and C.

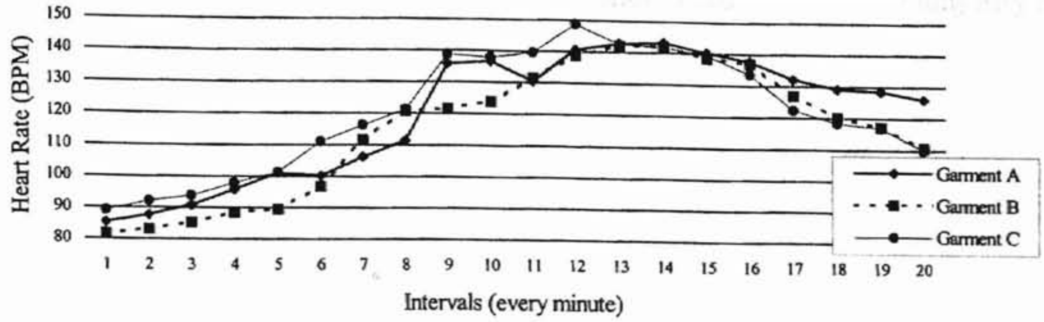


Figure 7. Mean Heart Rate by Garment-Across-Time

Results of analysis of variance for heart rate indicated a significant garment (F = 3.01, p = .0506) and time (F = 21.50, p < .0001) effect, as shown in Table 3. The significant time effect was expected, as each subject's heart rate fluctuated during the exercise protocol that included a warm-up period and a cool-down period. There were no significant differences indicated for subject, subject-by-garment, or garment-across-time.

Table 3. ANOVA: Heart Rate

Source	DF	SS	MS	F value	P level
Subject	5	85681.3889	17136.2778		
Garment*	2	1974.0222	987.0111	3.01	0.0506
Subject-x-Garment	10	3157.4111	315.7411		
Time***	19	133789.5444	7041.5550	21.50	<.0001
Garment-x-Time	38	5427.0889	142.8181	0.44	0.9986
Error	285	93471.8667	327.9715		

*p ≤ .05. **p = .001. ***p <.0001.

Skin Temperature

Mean skin temperatures for all garment treatments are shown in Figure 8. There was a fairly consistent trend for subjects wearing garment A to experience the lowest skin temperature for most of the test. Subjects wearing garment C had consistently higher mean temperature readings over the first thirteen minutes. Subjects wearing garment B had the next highest mean temperature readings until the fourteenth minute and subjects wearing garment A had the lowest mean temperature readings over the majority of the test.

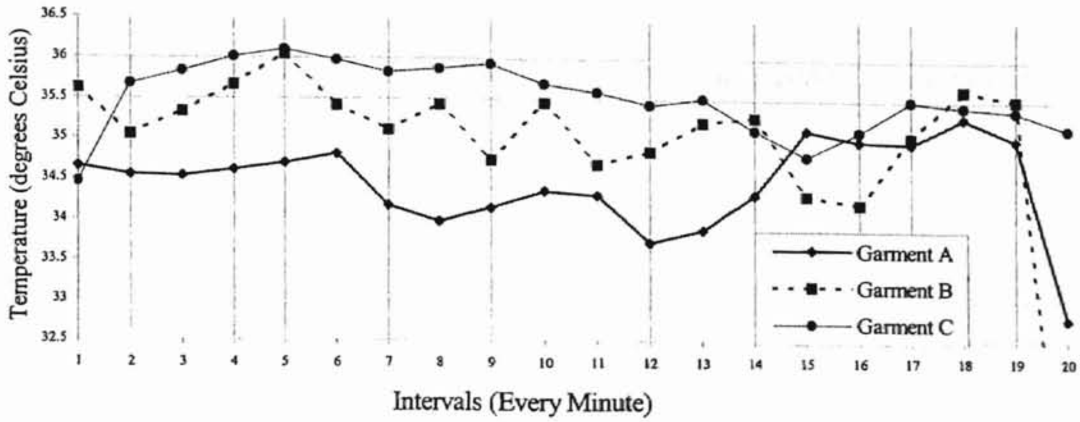


Figure 8. Mean Skin Temperature by Garment-Across-Time

Analysis of variance of skin temperature indicated only a significant time effect (F = 2.25, p = .0023), as shown in Table 4. The significant time effect was expected, as each subject's skin temperature would be expected to fluctuate during the exercise protocol, which included a warm-up and a cool-down period.

Table 4. ANOVA: Skin Temperature

Source	DF	SS	MS	F value	P level
Subject	5	967.782621	193.556524		
Garment	2	69.038134	34.519067	0.26	0.7768
Subject-x-Garment	10	1332.288276	133.228828		
Time*	19	137.707483	7.247762	2.26	0.0023
Garment-x-Time	38	125.036933	3.290446	1.03	0.4337
Error	285	914.122319	3.207447		

*$p \leq .05$.

Sweat Rate

In general, sweat rate increased over the test for subjects in all three garment treatments, as shown in Figure 9. Initially, sweat rate was similar for subjects regardless of garment. After four minutes, subjects wearing garment B started to experience higher sweat rates. Subjects wearing garment A experienced lower sweat rates during the last half of the test. Subjects wearing garment C experienced an elevated sweat rate in the last third of the test.

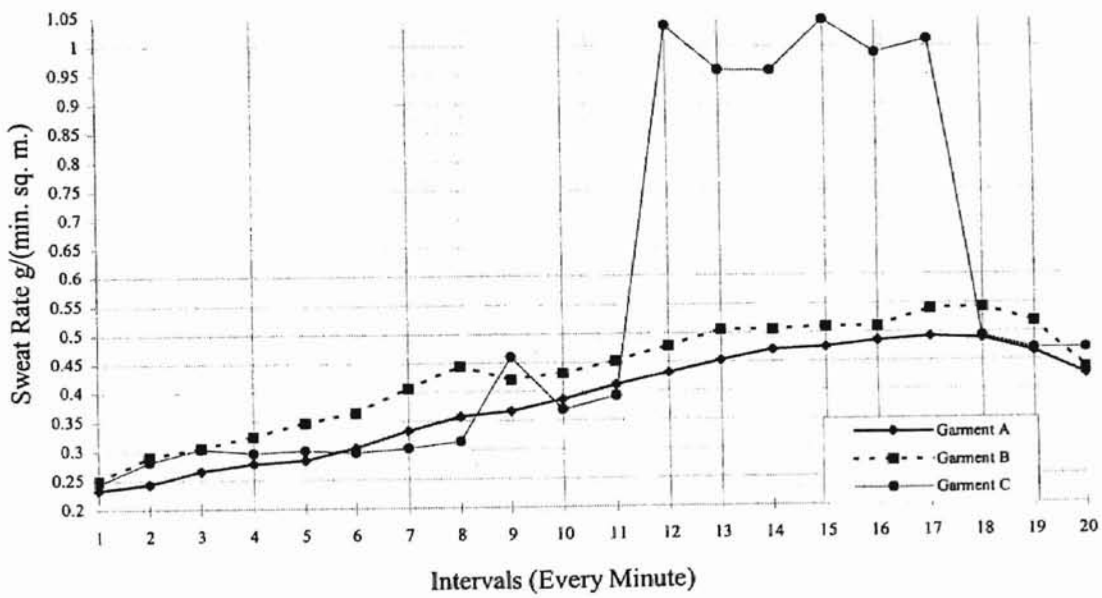


Figure 9. Mean Sweat Rate by Garment-Across-Time

Analysis of variance of sweat rate indicated only significant time effect ($F = 2.86$, $p < .0001$), as shown in Table 5. The significant time effect was expected, as each subject's sweat rate would be expected to fluctuate during the exercise protocol, which included a warm-up and a cool-down period.

Table 5. ANOVA: Sweat Rate

Source	DF	SS	MS	F value	P level
Subject	5	11.43051139	2.28610228		
Garment	2	1.65287722	0.82643861	0.84	0.4592
Subj-x-Garment	10	9.81279611	0.98127961		
Time***	19	8.12190528	0.42746870	2.86	<.0001
Garment-x-Time	38	4.89746722	0.12888072	0.86	0.7012
Error	285	42.55734250	0.14932401		

*$p \leq .05$. **$p = .001$. ***$p < .0001$.

Pre- and Post-Weights

Weight gain was calculated by subtracting each garment's pre-test weight from its post-test weight after each test session. Analysis of variance of pre- and post- weights indicated a significant garment effect ($F = 545.05$, $p < .0001$), with garment A gaining the most weight at 4.25 g. Garment B gained the next highest weight at .99 g., and garment C gained the least at .5 g. Although weight gain in itself does not appear to be beneficial, it does indicate that garment A absorbed more moisture. The absorption of moisture can result in more comfort by eliminating excess perspiration.

Motion Analysis

As a control, previous research projects video-taped subjects running on a treadmill in the nude (Haycock, Shierman, & Gillette, 1978; Lorentzen & Lawson, 1987; and Lawson & Lorentzen, 1990). Researcher LaJean Lawson says, high speed film of the naked breast during running shows the breast stretches and distends considerably with each footstrike (Walzer, 1990, p 66). Earlier studies support the findings that the greatest relative displacements are in the vertical directions. Therefore, for purposes of this study, subjects were asked to engage in the same type, duration, and intensity of exercise, which would produce vertical body movement, for the testing of all three garment treatments.

As such, vertical breast displacement was the only dependent variable, for motion analysis, investigated in this study.

Breast Displacement

The reflective markers placed on the sternal angle and both bust points identified body and breast reference points that provided data used to determine vertical breast displacement for each garment. It is important to realize that motion analysis is a step-by-step process. First, breast and body motion must be recorded to determine the high and the low elevations (the rise and fall) of the body and breast during the exercise protocol. Figure 10 provides an example of the raw data evaluated for each subject and garment treatment.

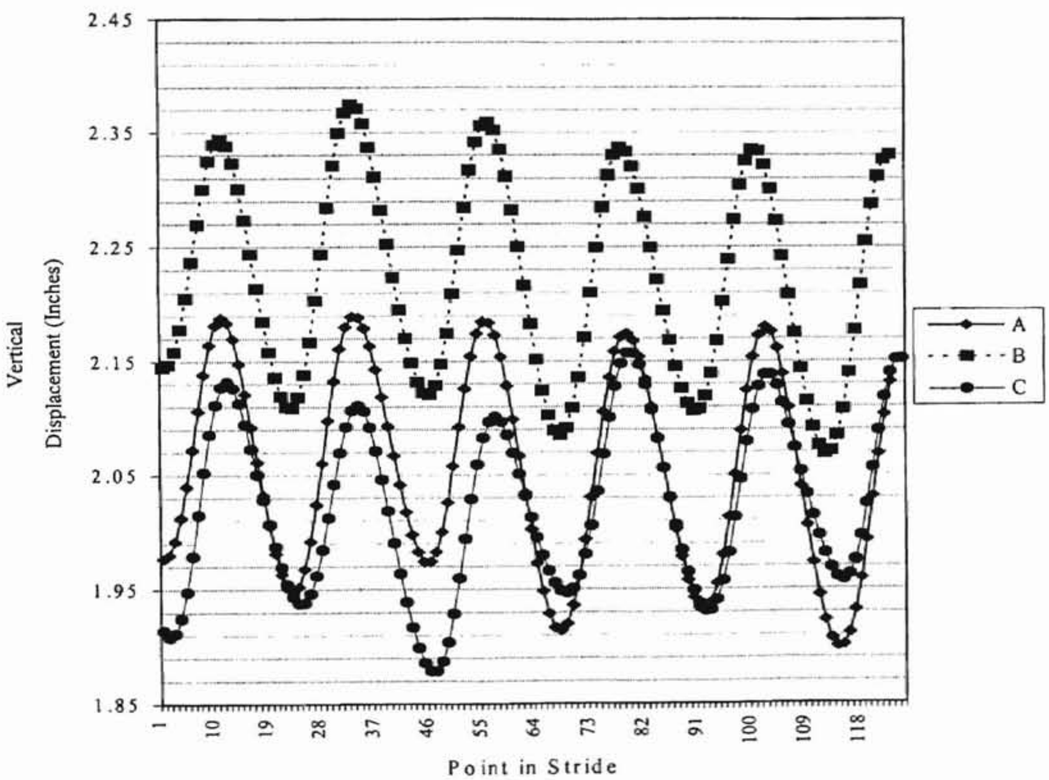
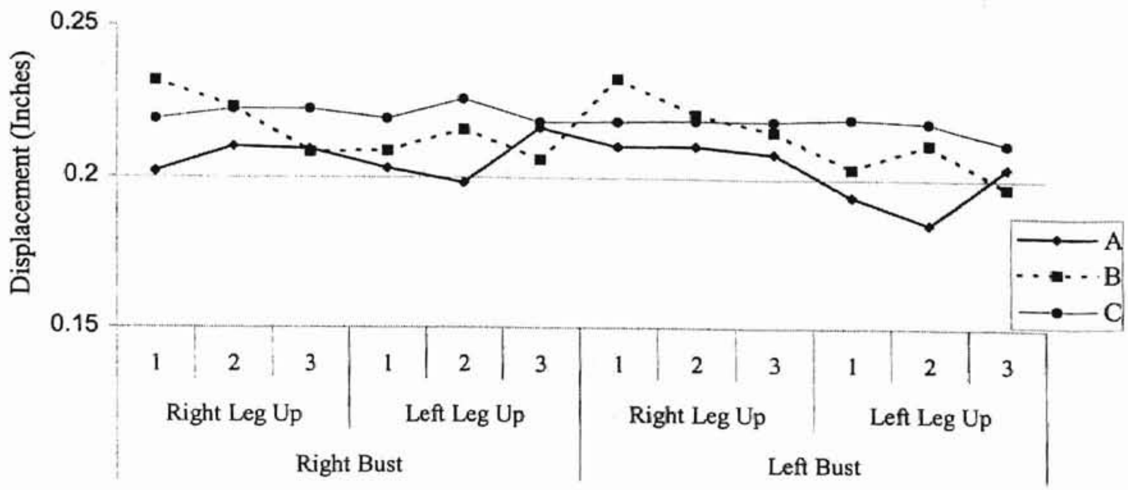


Figure 10. Vertical Breast Displacement

Tracking one stride includes both a left and a right heel strike. Therefore, the displacement was calculated for each leg on each stride. Three running strides were analyzed for this study yielding six measurements of displacement for each subject, breast, and leg. The total amount of vertical breast displacement for each subject and each garment was determined by finding the differences between the maximum and minimum vertical breast positions found over each of three running strides. Each individual's breast displacement was averaged to provide data by garment.

Figure 11 shows the average breast motion for each garment treatment, broken out by breast (right and left breast), stride (right and left leg), and repetition (1,2,3). There appears to be a trend for subjects wearing garment A to experience lower levels of breast displacement over the majority of the test, followed closely by subjects wearing garment B. Subjects wearing garment C appear to have experienced higher levels of vertical breast displacement over the majority of the test. As shown in Figure 11, the right and left step displacements are slightly different, as are the right and left breast displacement themselves.



Mean Right Bust Motion Mean Left Bust Motion

Figure 11. Average Bust Motion

The previous graph provided information on breast motion. Since it is not absolute breast motion that matters, but breast motion relative to trunk motion, it was necessary to calculate this difference. Trunk motion was calculated using the above process, repeated for the sternum. These values were subtracted from the breast displacement values to determine the relative breast displacement. Note that Figure 12 presents the difference between body and breast displacement averaged over breast, stride, and repetition for each garment treatment. The data show that subjects wearing garment C experienced greater breast displacement, as seen in the previous figure. Subjects wearing garment C experienced a mean displacement of .045 inches, a 68% higher level of displacement than the .031 inches experienced by subjects wearing garments A and B.

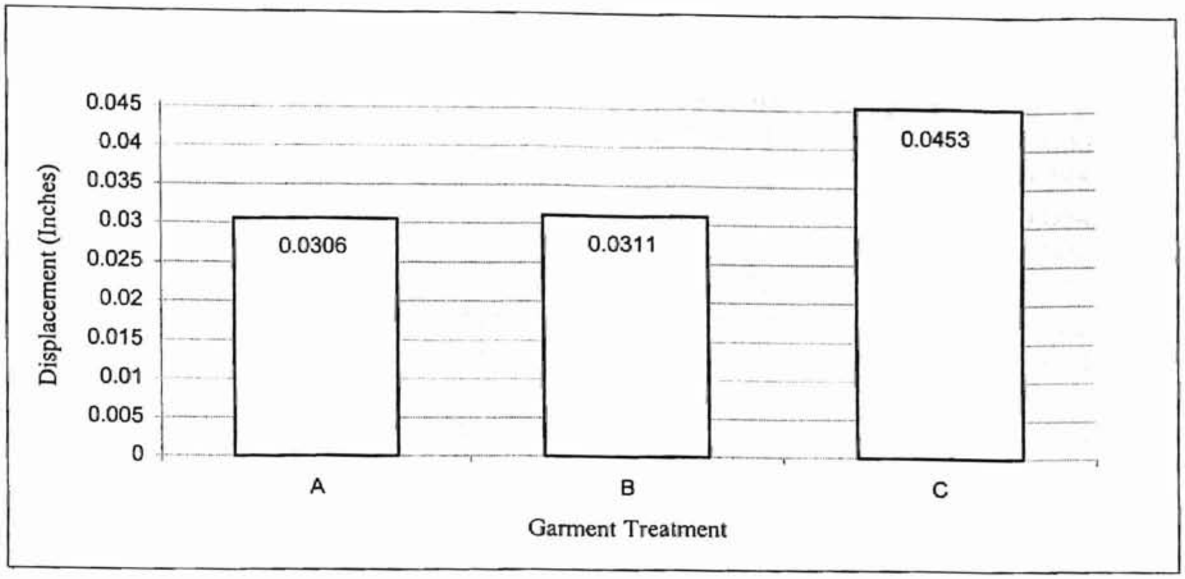


Figure 12. Average Breast Displacement Per Garment

In addition to graphing, ANOVA was used to determine significant difference for this data. ANOVA found a significant difference by subject, garment, and subject-in-garment interaction for relative breast displacement (see Table 6). The significant difference by subject ($F = 55.47$, $p < .0001$) was expected, because each person possesses not only a difference in breast mass for both breasts, but a difference in age, number of children, skin tissue, ligaments, and levels of fitness. A significant difference by garment was predicted since garments A and B (both encapsulation style) were designed to provide support for the breasts, and the data support this prediction. Table 7 shows the displacement interaction between garment treatments. There was no significant displacement difference between garments A and B, as shown in Table 10.

Table 6. ANOVA: Biomechanical Displacement

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Subject***	5	0.02768554	0.00553711	55.47	<.0001
Leg	1	0.00007571	0.00007571	0.76	0.3851
Bust	1	0.00034561	0.00034561	3.46	0.0645
Garment***	2	0.00950675	0.00475337	47.62	<.0001
Subject-x-leg	5	0.00054168	0.00010834	1.09	0.3703
Subject-x-bust	5	0.00024265	0.00004853	0.49	0.7863
Subject-x-garment***	10	0.01544646	0.00154465	15.47	<.0001
Bust-x-garment	2	0.00003161	0.00001581	0.16	0.8537
Subj-bust-x-garment	10	0.00118221	0.00011822	1.18	0.3045
Error	172	0.01717050	0.00009983		

$^{*}p \leq .05$. $^{**}p = .001$. $^{***}p < .0001$.

Table 7. Tukey's Studentized Range (HSD): Displacement

Garment Comparison	Difference Between Means	Simultaneous 95% Confidence Limits	
Garment C – A***	0.013745	0.009780	0.017710
Garment C – B***	0.014210	0.010273	0.018147
Garment A – C***	-0.013745	-0.017710	-0.009780
Garment A – B	0.000465	-0.003500	0.004430
Garment B – C***	-0.014210	-0.018147	-0.010273
Garment B – A	-0.000465	-0.004430	0.003500

Comparisons significant at the 0.05 level are indicated by ***.

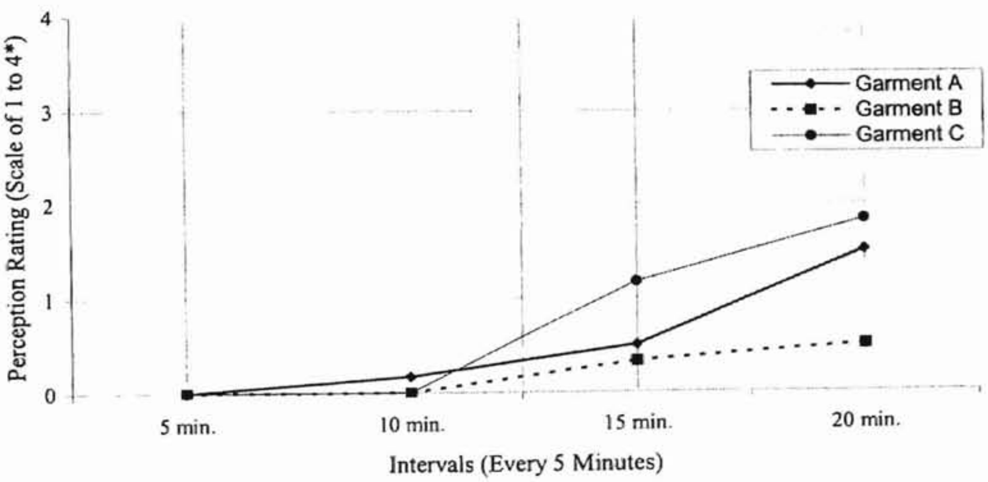
Perceived Comfort

Psychological comfort descriptors examined included descriptors related to moisture perception, thermal perception, tactile comfort, and overall comfort. Five of the comfort descriptors had positive connotations, while seven of the comfort descriptors had negative connotations. Moisture descriptors included descriptors such as absorbent, clammy, clingy, dry, and wet. Two descriptors related to thermal perception included hot and warm. Tactile comfort descriptors included descriptors such as itchy, smooth, and soft. Breathable and confining were the two descriptors related to overall comfort. Graphs for ten of the comfort descriptors may be found in Appendix G.

Subjects used five intensity levels to describe their perceptions of each descriptor on the comfort ballot. These levels were as follows: not at all (0), partially (1), mildly (2), definitely (3), and totally (4).

Perceived Comfort - Wet Descriptor

There is a significant garment-by-time interaction for the moisture sensation of wetness. As expected, perception of wetness increased over time regardless of garment treatment, although the highest mean reading was 1.9 or mildly wet (see Figure 13). Subjects wearing garment C perceived a greater wetness for the last half of the test than subjects in the other bras. Subjects wearing garment A experienced the next highest intensity of wetness, and those wearing garment B reported the lowest perception of wetness.



*Note: 5 Point Rating Scale: 0 = not at all, 1 = partially, 2 = mildly, 3 = definitely, 4 = totally

Figure 13. Perception Rating of the Descriptor: Wet

These results are interesting when considering the pre- and post-weight data. Recall garment A had the highest weight gain at 4.25 g., yet the subjects did not perceive garment A as the wettest bra. Combined with the pre- and post-weight data, the results suggest the complexity of dynamic moisture transfer between sweating skin and clothing fabrics. ANOVA found a significant difference for time ($F = 23.49$, $p < .0001$) and the garment-by-time interaction ($F = 2.80$, $p = .0211$), as shown in Table 8. This garment-by-time interaction indicates that there are significant differences by garment during difference points in time during the exercise protocol.

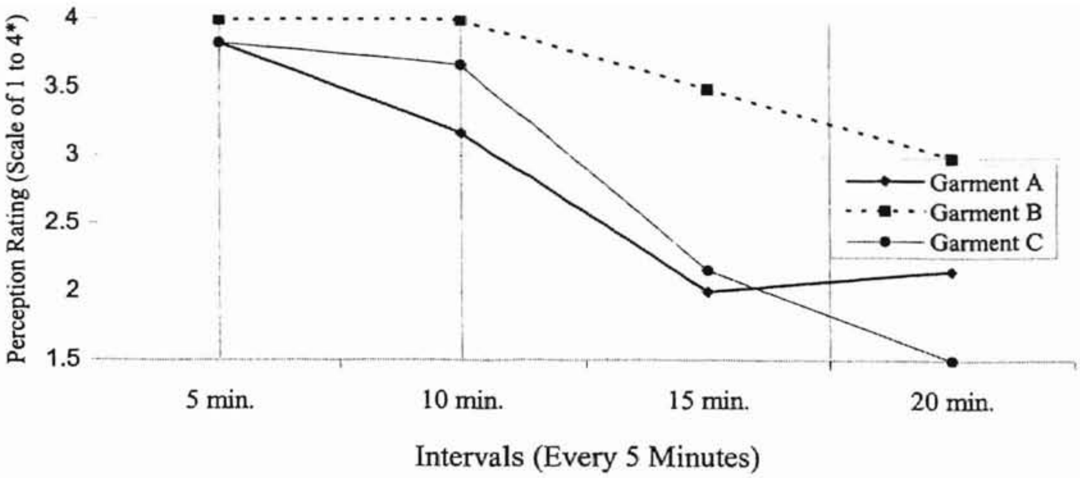
Table 8. ANOVA: Perceived Rating of the Descriptor: Wet

Source	DF	SS	MS	F value	P level
Subject	5	2.3333	0.4666		
Garment	2	3.5833	1.7916	3.21	0.0838
Subject-x-Garment	10	5.5833	0.5583		
Time***	3	19.4444	6.4814	23.49	<.0001
Garment-x-Time*	6	4.6388	0.7731	2.80	0.0211
Error	45	12.41666667	0.27592593		

*$p \leq .05$. **$p = .001$. ***$p < .0001$.

Perceived Comfort - Dry Descriptor

The graph for the descriptor dry, as shown in Figure 14, presents an inverse trend as compared to the wetness graph (Figure 12). Generally, all subjects wearing all treatments reported being totally dry for the first ballot. Subjects wearing garment B reported the highest perception of dryness over the test. Subjects wearing garments A and C reported similar dryness perceptions.



*Note: 5 Point Rating Scale: 0 = not at all, 1 = partially, 2 = mildly, 3 = definitely, 4 = totally

Figure 14. Perception Rating of the Descriptor: Dry

ANOVA found a significant difference by garment and time for the dry descriptor. Table 9 shows this significant difference for garment ($p = .0286$) and for time ($p < .0001$).

Table 9. ANOVA: Perceived Rating of the Descriptor: Dry

Source	DF	SS	MS	F value	P level
Subject	5	1.0694	.2138		
Garment**	2	11.1111	5.5555	5.18	.0286
Subject-x-Garment	10	10.7222	1.0722		
Time***	3	35.0416	11.6805	17.12	<.0001
Garment-x-Time	6	6.0000	1.0000	1.47	.2117
Error	45	30.70833333	0.68240741		

*p = .05. **p = .001. ***p <.0001.

Perceived Comfort – Other Descriptors

There are no significant differences due to garment or time for the tactile sensation of itchy. Subjects wearing garment C reported the highest perception of itchiness with a rating of 1, which indicated that the subject perceived the garment to be partially itchy. Subjects wearing garments A and B reported no perception of itchiness.

All other descriptors had a significant effect due to time only. Subjects wearing garment C reported a consistent drop in their perception of absorbency in bra C throughout the test. Subjects wearing garments A and B reported a rise in their perception of absorbency for the first half of the test, followed by a consistent decline for the last half of the test. Subjects reported similar results for the descriptor breathable as previously described for the descriptor absorbent. Subjects wearing garment C experienced an increase of clamminess over the last half of the test, ending with a rating of 2.5, indicating a definite perception of the bra being mildly clammy. Subjects wearing garment A perceived a level of 1.5 over the last five minutes of the test, which indicated a mild sensation of clamminess. Subjects wearing garments B did not report the perception of clamminess. Garment C was rated as mildly confining, while garment A was rated as partially confining, and garment B was not perceived as confining. All three garment treatments were perceived as smooth and soft, declining only a small amount at the end of the test. Subjects wearing garment C reported an increase in their perception of heat, from not at all to approximately, definitely warm and hot. Subjects wearing garments A and B reported an increase in their perception of heat, from not at all to mildly hot and definitely warm.

Conclusions and Implications

Garments A and B are similar in that they both have encapsulation and compression styling, whereas, garment C is solely compression styling. Thus, the differences between garments A and B lie in design features and the combination of fabrics used. In addition, it is noteworthy to note that garment A (prototype) covers a larger amount of the body surface than either garment B or C. Although sports bras cover only a small portion of the body, they affect the physiological data tested. It is hypothesized that the combination of fabric and garment characteristics explains the results. A summary of experimental findings is shown in Table 10.

Table 10. Summary of Experimental Findings

	Time	Garment	Garment-over-Time	Subject	Subject-by-Garment	Garment A	Garment B	Garment C
Heart Rate	significant	significant					Lowest mean HR	Highest mean HR
Skin Temperature	significant					Lowest mean ST		Highest mean ST
Sweat Rate	significant					Lowest mean SR	Highest mean SR	SR spiked for six min.
Moisture Gain						4.25 g	0.99 g	0.5 g
Vertical Breast Displace-ment		significant		significant	significant	0.0306 in.	0.0311 in.	0.0453 in.
Absorbent	significant							
Breathable	significant							
Clammy	significant							
Clingy	significant							
Confining	significant							
Dry	significant	significant				Mildly dry at 20 min.	Most dry	Partially to Mildly dry at 20 min.
Hot	significant							
Itchy								
Smooth	significant							
Soft	significant							
Warm	significant							
Wet	significant		significant			Partially to mildly wet at 20 min.	Partially to mildly wet at 20 min.	Most wet

There was a general trend for heart rate to increase over the first twelve minutes and gradually decline over the last eight minutes; forming a type of a bell curve (Figure 7), which indicates a time effect. ANOVA indicated a significant difference in heart rate by garment and time (Table 3). Overall, subjects wearing garment C experienced the higher heart rate. Motion analysis data also indicated that subjects wearing garment C experienced higher levels of vertical breast displacement.

ANOVA indicated significant difference in skin temperature across time (Table 4); yet, there is a clear trend for garment effects as indicated by the means. Overall, subjects wearing garment C experienced higher skin temperatures, followed by subjects wearing garment B (Figure 8). Subjects wearing garment A (prototype) experienced the overall lower skin temperature. The results are surprising, given that the garments cover such a small amount of body surface. Again, motion analysis data indicated that subjects wearing garment C experienced higher levels of vertical breast displacement. There was a significant difference between pre- and post-weights, with garment A (prototype) gaining the most weight and garment C gaining the least. This data supports the notion that fabric absorption affects skin temperature; therefore, affecting comfort.

Sweat Rate increased over the test for subjects in all three garment treatments and ANOVA indicated only a significant time effect; yet, again there was a clear trend for garment differences. Overall, subjects wearing garments B experienced higher sweat rates over the first eleven minutes. At the eleventh minute, subjects wearing garment C experienced elevated sweat rates for seven minutes. This spike in sweat rate for subjects wearing garment C cannot be explained. There was a general trend for subjects wearing garment A (prototype) to experience the lowest sweat rate over the entire test. It is important to remember that garment A (encapsulation and compression styling), which was lined with Hydrofil®, covered the largest portion of body surface and gained the most weight. These garment characteristics could account for the lower sweat rate experienced by subjects wearing garment A.

Figure 11 indicates a trend for subjects wearing garment C to experience the highest breast motion and subjects wearing garment A to experience the lowest breast motion. Figure 12 also indicates that subjects wearing garment C experienced the highest amount of relative breast displacement with a mean of .045, but the differences of breast displacement between subjects wearing garments A (prototype) and C are small. In support of this data, ANOVA found a significant difference for subject, garment, and the subject-by-garment interaction for relative breast displacement. There were significant differences between garments A (prototype) and C, as well as between garments B and C. There was no significant difference between garments A (prototype) and B. Most people are not symmetrical and each breast moves differently, therefore it is necessary to track the movement of both breasts. It is obvious that if no two breasts are created equal, then no two people are built the same and differences by subject are expected. In the same light, subject-by-garment differences were expected, especially combining different garment characteristics with unique individuals. Finding significant garment differences was positive, as this was the focus of the study.

ANOVA indicated a significant garment-over-time interaction for the moisture sensations of wet and dry. There was a general trend for subjects wearing garment C to perceive higher intensity of wetness and subjects wearing garment B to perceive the lowest intensity of wetness. Garment A (prototype) fell between the other two sports bras, which is noteworthy, because garment A had the greatest weight gain and yet was not perceived to be the wettest.

The data show an inverse response to the comfort descriptor dry, with subjects wearing garment B perceiving a higher intensity of dryness. There the data vary, with subjects wearing garment A (prototype) perceiving the lowest intensity of dryness and garment C falling in between the other two sports bras. These data show garment A to have been perceived as the least dry for the first fifteen minutes of the test session and yet, not the wettest garment treatment. This appears to be conflicting data, but again, it is important to remember that garment A gained the most weight during each test session, which indicates that it absorbed the most sweat.

At the beginning and end of each test session, the researcher assisted the subjects by hooking or unhooking the sport bra as needed. A towel and alcohol wipes were offered to each subject at the end of each test session. Often, subjects asked the researcher to wipe up excess sweat with a towel and sometimes wipe their back with an alcohol wipe, before donning their street clothes. During these times, the researcher noted that subjects wearing garment C appeared to have perspiration running down the front and back of their chest. Subjects wearing garment B appeared to have an excess of perspiration on the front and back of their torso, but it did not seem to be running down their torso as when they exercised in garment C. The least amount of perspiration standing on the subjects' bodies seemed to be when subjects exercised in garment A. The above observations are not data, shouldn't be considered as such, they are only meant to aid in interpreting the data. The researcher speculates that this phenomena was either due to the fact that garment A covered more of the subjects' body surface, the inner bra of Hydrofil® nylon, or a combination of the two.

Convenience, along with economics and lifestyle, plays an important role in how a woman perceives a garment. This poses a real design challenge for the sports bra designer, as every woman is unique; therefore, no single style of sports bra will be the perfect sports bra for every woman. Garment A, prototype sports bra, was predicted to be perceived as more supportive and comfortable than garment C, a compression style sports bra and the most commonly available sports bra. It was predicted that Garment A (encapsulation style) would be perceived to be as supportive and as comfortable as garment B (encapsulation style), if not better. The data support both predictions.

The results of this study support the findings of previous research studies and the need for firm breast support, particularly among large-breasted women (Gehlsen & Albohm, 1980; Haycock, 1978; Hunter & Torgan, 1982; Lorentzen & Lawson, 1987; Schuster, 1979). If, as these studies imply, larger-busted women require different support and design systems, should the current industry practice of designing bras for various cup sizes in exactly the same way be changed or at least investigated?

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CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Female participation in sports and active recreation has increased dramatically, due to legislation mandating equal access for both females and males to sports opportunities and to a strong societal emphasis on physical fitness. Instantaneous publicity, following Brandi Chastain's brandishment of her sports bra, after scoring the winning shot in the World Cup Soccer Final, forced sports bras to the forefront of athletic wear.

Sports bras differentially designed for various bra cup sizes might alleviate breast discomfort experienced by some women, particularly large breasted women. Such an improvement in support and comfort could be an important step toward promoting healthy physical activity and safer sports participation for women of all sizes. The purpose of this study was to compare a prototype sports bra previously designed for large-busted women with two commercially available sports bras through a controlled laboratory wear study conducted under selected environmental conditions. The three sports bras differ in style and fabric composition. Quantitative and qualitative measures of support, movement, and comfort were assessed during an exercise protocol using large-breasted female subjects.

Testing Protocol

Testing took place in a controlled environmental chamber under selected environmental conditions of 75° F ± 1° F and 40% RH ± 5%. Six females (mean age of 34), with approximately the same bust size and who successfully completed the pre-screening process, participated in this study. Physiological data (heart rate, skin temperature, and sweat rate) were collected every minute during the exercise protocol. Pre- and post-test weights of all three sports bras were measured and averaged. Recognizing the importance of perceptual data in detecting subjects' perceptions of clothing comfort, a comfort scale using both negative and positive descriptors with a 5-point response scale was used at five-minute intervals throughout the experiment to evaluate the perceived comfort of the sports bra. Biomechanical data were collected over the first three running strides of the exercise protocol and analyzed frame-by-frame. The data were graphed over-time and analyzed by ANOVA and Post Hoc procedures as appropriate to present and compare the support and comfort properties of the three sports bras.

Conclusions

The results of this study indicate that no single style of sports bra received superior marks on all criteria: control of vertical breast displacement, subjective comfort ratings, and physiological data. When comparing the three garment treatments, there was a general trend for the encapsulation styled sports bras, garments A and B, to be comparable across the entire study. A summary of experimental findings is shown in Table 10 (see Chapter IV, p. 73). Subjects wearing garments A and B had a lower level of vertical breast displacement of .031" as compared to the subjects wearing garment C with .045" of displacement. Thus, sports bras that have both compression and encapsulation styling are more supportive than only compression styled sports bras. Based on the results of this and previous study, large-busted women should wear sports bras that have both compression and encapsulation styling for greater support.

Garment B was perceived to be the driest. Heart rate data followed a general pattern of increasing over the first three-quarters of the test, with subjects wearing garment C generally experiencing a higher mean heart rate over that same time period. Skin temperature data for all three-garment treatments varied. Garment A scored the lowest over the majority of the test. Individual variation in skin temperature undoubtedly contributed to the lack of significant difference by subject and by subject-in-garment. Sweat rate for garments A and B again followed closely the same pattern, whereas subjects wearing garment C experienced a hike in sweat rate over the last seven minutes of the jog. It is interesting to note that weight gain and sweat rate appear to be related. Garment A gained the most weight over the exercise protocol indicating its adeptness at absorbing moisture. The lack of wicking or moisture dissipation could be due to a shortage in time. In general, garments A and B scored higher on comfort and support, with A and B interchanging over variables.

Fit was varied even with considerable care in pre-screening for similar size-range and breast mass. Locating large-busted women who regularly jog or run for any length of time was difficult, therefore the size criteria was lowered somewhat. All participants wore size D or DD, but were smaller around the rib cage and wore a smaller band size than expected. A smaller band size will result in a reduction of breast mass. Attaining a homogeneous subject population is difficult at best, especially when bust size is also a requirement. There were extremes of life styles and experiences represented within this group of women, who ranged between the ages of 22 and 37 years. Data may have varied due to these individual differences. A more homogeneous subject population would definitely have been beneficial. Perception of comfort was more than likely affected by these individual life styles and experiences; as well as, by personal likes and dislikes.

Recommendations for Further Research

The following recommendations for further research were stated:

1. Conduct a similar investigation with a larger, more homogeneous, subject population, such as, the subject population being the same age.
2. Conduct a field study in which athletes, such as contact, non-contact wear prototype sports bras during daily workouts.
3. Conduct a complementary textile testing, in which a variety of thermal and moisture transportation properties of all given materials, both individually and in combination, could be studied.
4. Conduct a similar investigation with the same garment design, but incorporating different textiles.
5. Conduct a similar investigation that would simulate problems experienced by females on the equestrian team, while trotting their horses around the arena.

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APPENDICES

APPENDIX A

FLYER

FREE Sports Bras

Do you fit these qualifications?

- Bra size: 38C or D, 36D or DD, or 34DD
- Good physical condition
- Exercise frequently

Then the Department of Design, Housing & Merchandising has a deal for you!

DHM is conducting research, which will involve wearing three different sports bras while jogging on a treadmill in an environmental chamber.

Subjects who complete the prescreening and the four test sessions, will be given three sports bras.

Test sessions will be conducted this spring.

If interested contact Cathy at 744-5035 or 624-0690

APPENDIX B

SUBJECTS' INFORMATION CARD

SUBJECTS' INFORMATION CARD

Name:________________________________

Address:________________________________

Phone number(s):____________________________

Email address:______________________________

Date of birth:______________________________

Do you frequently jog or run?________________________

Are you physically able to jog for 15 minutes at 5 miles per hour?____________

Would you be willing to jog on a treadmill for 15 minutes at 5 miles per hour?________

Have you had breast augmentation?________________________

Bra Measurements:

High bust: ____________________

Full bust: ____________________

Under bust: ____________________

Center front: ____________________

Bra size: ____________________

Schedule:

Times available: ____________________

____

____

____

____

APPENDIX C

SUBJECTS' CONSENT FORM

CONSENT FORM FOR SUBJECTS ACCEPTED FOR SPORTS BRA STUDY

- "I, ____________________________, understand that Cathy Starr and Grace Krenzer have developed a sports bra prototype, as part of a graduate course in Functional Design, under Dr. Donna Branson's (Oklahoma State University, Department of Design, Housing & Merchandising) direction.
- This was done as part of an investigation entitled *Biomechanical and Thermal Comfort Analysis of a Prototype Sports Bra*.
- The purpose of this investigation is to compare the prototype sports bra previously developed using a systematic design process with two commercially available sports bras.
- Confidentiality of records will be maintained by using the mean data, at no time will an individual's responses be given, and records and data will be kept in a locked file that only the researchers will have access to.
- I understand that I will be given a custom-made prototype sports bra and two manufactured sports bras.
- I understand that I will need to wear the assigned sports bra while exercising on a treadmill for 15 minutes. Each exercise phase will begin with a fast walk for 3 minutes, followed by an increase to a 6 mph jog on a flat grade for 10 minutes, and lastly, a gradual reduction in speed to a slow walk for a 2-minute cool down.
- I understand that I will be permitted to keep all three sports bras after I have completed all parts of the study.
- I understand that my participation is voluntary; that there is no penalty for refusal to participate, and that I am free to withdraw my consent and participation in this project at any time without penalty after notifying Cathy Starr and/or Dr. Donna Branson.
- I understand that if I experience any discomfort while participating in the controlled laboratory wear study, I should immediately notify Cathy Starr or contact Dr. Branson at (405) 744-5035 (9:00-5:00). I may also contact Sharon Bacher, IRB Executive Secretary, 203 Whitehurst, Oklahoma State University, Stillwater, OK 74078; telephone number: (405) 744-5700.

I have read and fully understand the consent form. I sign it freely and voluntarily. A copy has been given to me.

Date:__________________________ Time:______________________(a.m./p.m.)

Signed: ____

Signature of Subject

"I certify that I have personally explained all elements of this form to the subject or his/her representative before requesting the subject or his/her representative to sign it."

Signed:____

Project Director or his/her authorized representative

APPENDIX D

PAR-Q AND PATTERN OF EXERCISE

Part I: Physical Activity Readiness Questionnaire

For most people, physical activity should not pose any problem or hazard. PAR-Q has been designed to identify the small number of adults for whom physical activity might be inappropriate or those who should have medical advise concerning the type of activity most suitable.

	Yes	No	
1.	❍	❍	Has your doctor ever said you have heart trouble?
2.	❍	❍	Do you frequently suffer from pains in your chest?
3.	❍	❍	Do you often feel faint or have spells of severe dizziness?
4.	❍	❍	Has a doctor ever said your blood pressure is too high?
5.	❍	❍	Has a doctor ever told you that you have a bone or joint problem such as arthritis that has been aggravated by exercise, or might be made worse with exercise?
6.	❍	❍	Is there a good physical reason not mentioned here why you should not follow an activity program even if you wanted to?
7.	❍	❍	Are you over 65 and not accustomed to vigorous exercise?

If a person answers yes to any question, vigorous exercise or exercise testing should be postponed. Medical clearance may be necessary.
Reference: PAR-Q Validation report. British Columbia Department of Health, June 1975 (Modified Version)

Part II: Pattern of Exercise

8. How frequently do you exercise? Check the most appropriate category.
   - ❍ Once a week
   - ❍ Two to three times a week
   - ❍ Four to five times a week
   - ❍ Six to seven times a week

9. How long do you typically exercise per session? Check the most appropriate category.
   - ❍ 15 minutes
   - ❍ 30 minutes
   - ❍ 45 minutes
   - ❍ 60 minutes
   - ❍ Over 60 minutes

10. How long have you maintained this exercise routine? Check the most appropriate category.
    - ❍ Weeks
    - ❍ Months
    - ❍ Years

11. What types of exercise do you participate in on a weekly basis? Check all that apply.

❍ Aerobics	❍ Running	❍ Martial Arts
❍ Fast Walking	❍ Jogging	❍ Racquetball
❍ Water Aerobics	❍ Cycling	❍ Tennis
❍ Weight Training	❍ Others (specify)____________	

12. After completing your exercise routine, how do you feel? Check the most appropriate category.
    - ❍ Revitalized
    - ❍ Accomplished
    - ❍ Winded
    - ❍ Exhausted
    - ❍ In need of emergency care

APPENDIX E

MEDICAL HISTORY ANALYSIS AND RELEASE FORM

MEDICAL HISTORY ANALYSIS

NAME____DATE______________

Please indicate if you have had any of the following medical conditions in the past.

	YES	NO	DATE
Heart attacks, coronary angioplasty, or cardiac surgery	☐	☐	____
Chest discomfort, especially with exercise	☐	☐	____
Lightheadedness or fainting with exercise	☐	☐	____
Shortness of breath with exercise	☐	☐	____
Rapid heartbeats or palpitations	☐	☐	____
Heart murmurs, clicks, or unusual cardiac findings	☐	☐	____
High blood pressure	☐	☐	____
Stroke	☐	☐	____
Ankle swelling	☐	☐	____
Peripheral arterial disease, claudication	☐	☐	____
Phlebitis, emboli	☐	☐	____
Pulmonary disease including asthma, emphysema and bronchitis	☐	☐	____
Abnormal blood lipids	☐	☐	____
Diabetes	☐	☐	____
Anemia	☐	☐	____
Emotional disorders	☐	☐	____
Recent illness, hospitalization or surgical procedure	☐	☐	____
Medications of all types	☐	☐	____
Drug allergies	☐	☐	____
Orthopedic problems, arthritis	☐	☐	____
FAMILY HISTORY OF:			
Coronary disease	☐	☐	____
Sudden death	☐	☐	____
Lipid abnormalities	☐	☐	____
HABITS:			
Caffeine use	☐	☐	____
Alcohol use	☐	☐	____
Tobacco use	☐	☐	____
Eating disorder	☐	☐	____

MEDICAL RELEASE FORM

NAME:________________________________ DATE______________

AGE:________________________________

This subject passes the qualifications pertaining to cardiovascular fitness.

Approved by: ____
Signature of Reviewer

APPENDIX F

OSU INSTITUTION REVIEW BOARD (IRB)

Oklahoma State University
Institutional Review Board

Protocol Expires: 4/22/02

Date Monday, April 23, 2001 IRB Application No HE0158

Proposal Title: BIOMECHANICAL AND THERMAL COMFORT ANALYSIS OF A PROTOTYPE SPORTS BRA

Principal Investigator(s):

Cathy Starr	Donna Branson
814 W.Seminole Dr.	447 HES
Stillwater, OK 74075	Stillwater, OK 74078

Reviewed and Processed as: Exempt

Approval Status Recommended by Reviewer(s) : Approved

Signature : Carol Olson

Carol Olson, Director of University Research Compliance

Monday, April 23, 2001
Date

Approvals are valid for one calendar year, after which time a request for continuation must be submitted. Any modifications to the research project approved by the IRB must be submitted for approval with the advisor's signature. The IRB office MUST be notified in writing when a project is complete. Approved projects are subject to monitoring by the IRB. Expedited and exempt projects may be reviewed by the full Institutional Review Board.

APPENDIX G

FIGURES

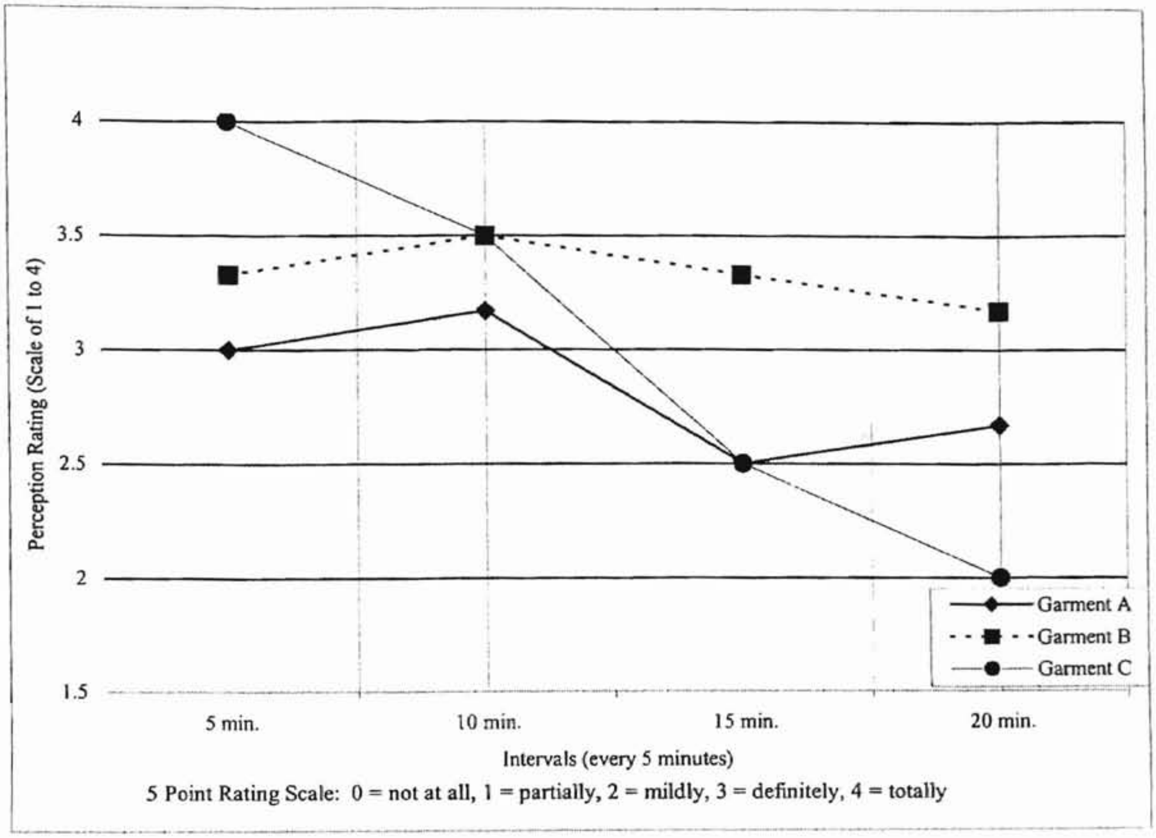


Figure 14. Perception Rating of Absorbence

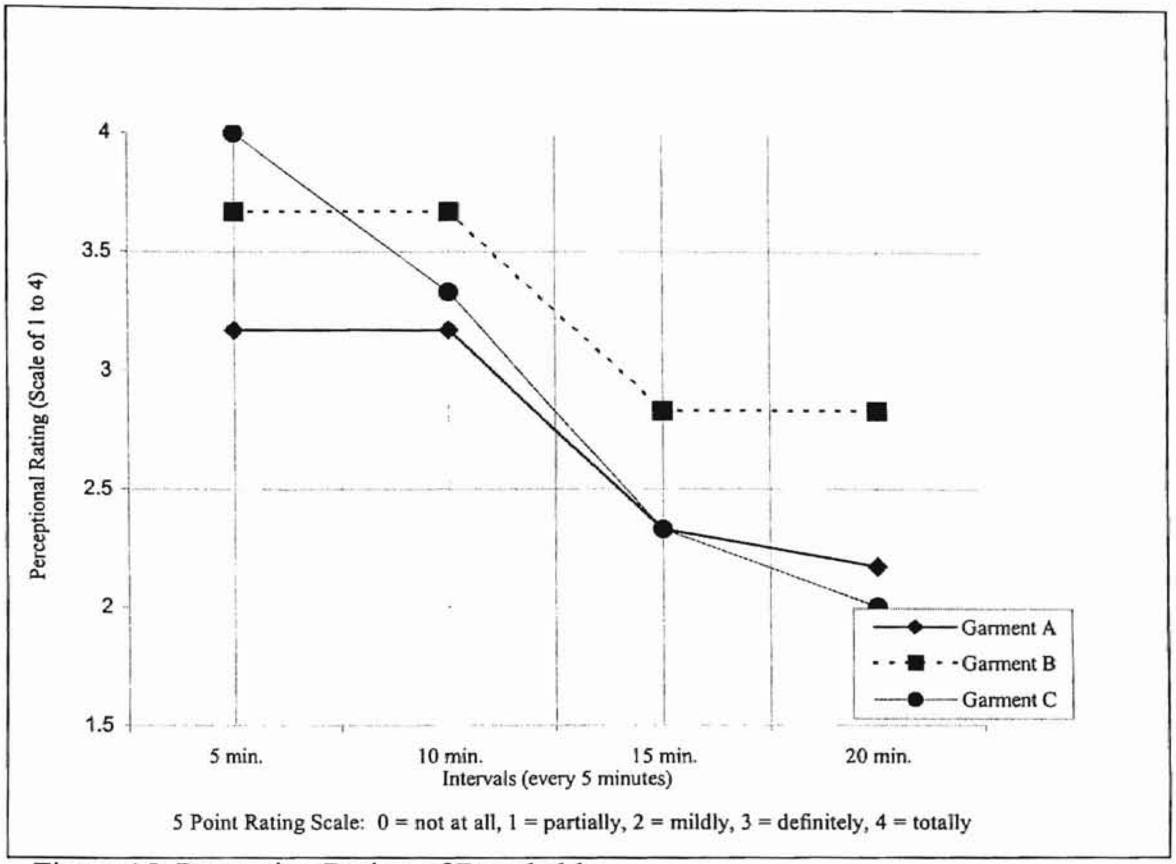


Figure 15. Perception Rating of Breathable

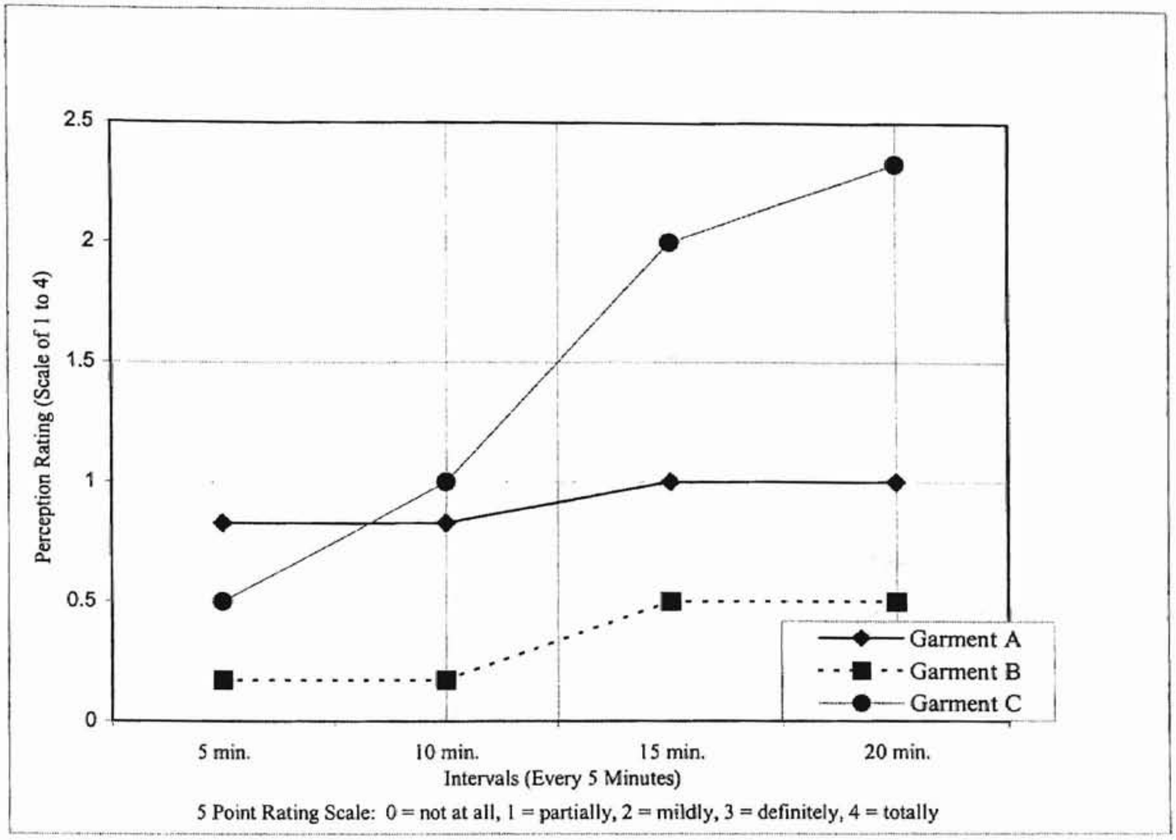


Figure 16. Perception Rating of Clingy

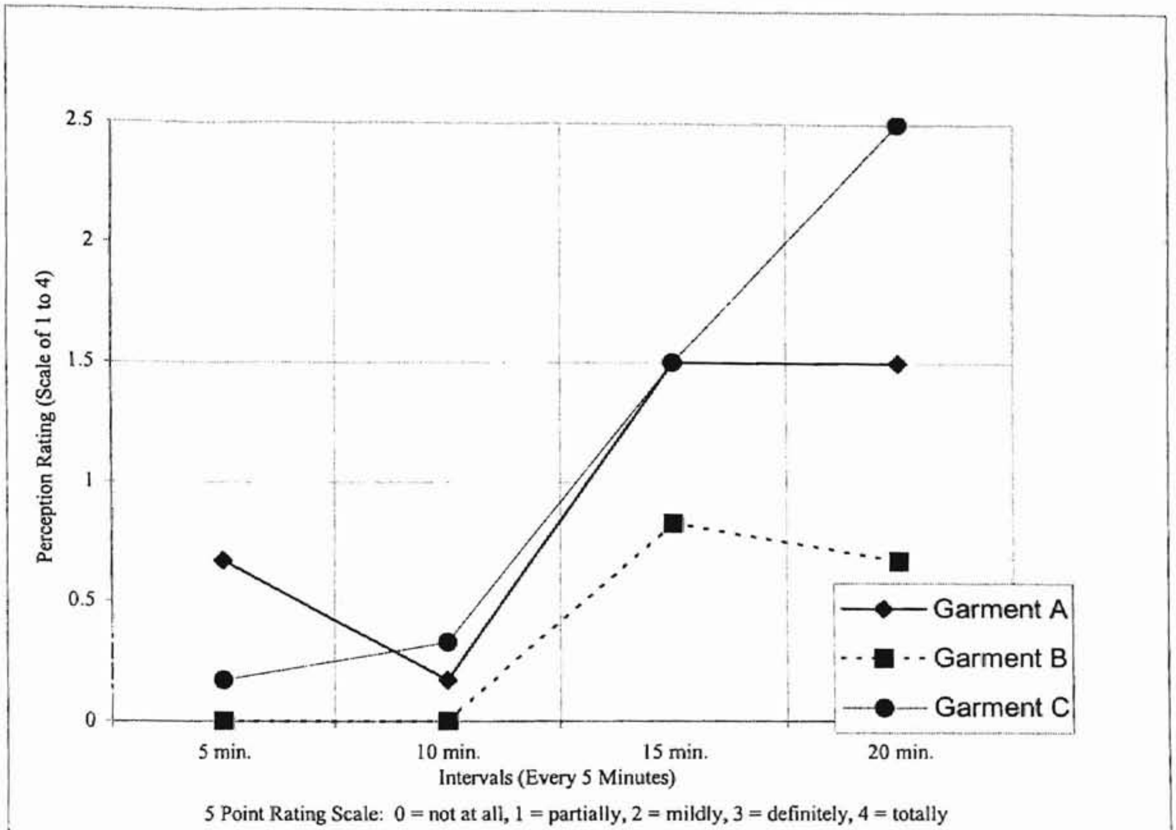


Figure 17. Perception Rating of Clamminess

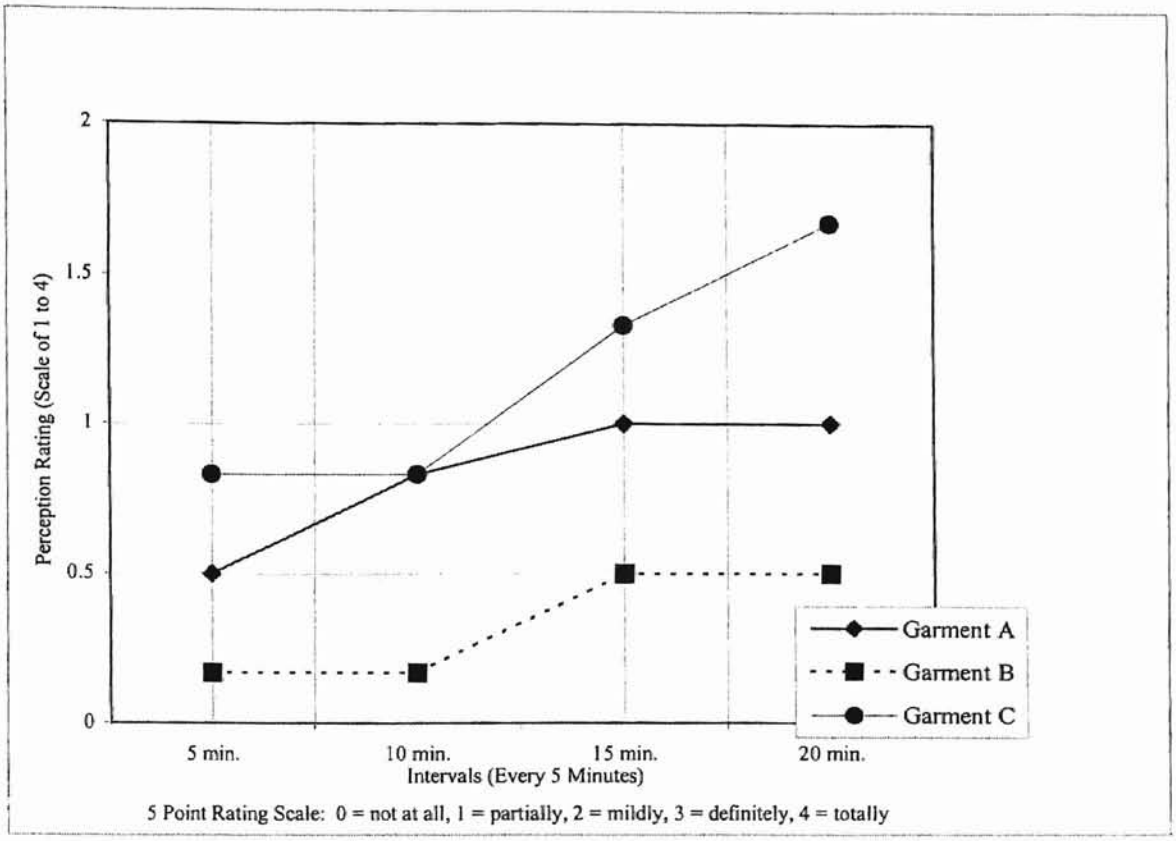


Figure 18. Perception Rating of Confining

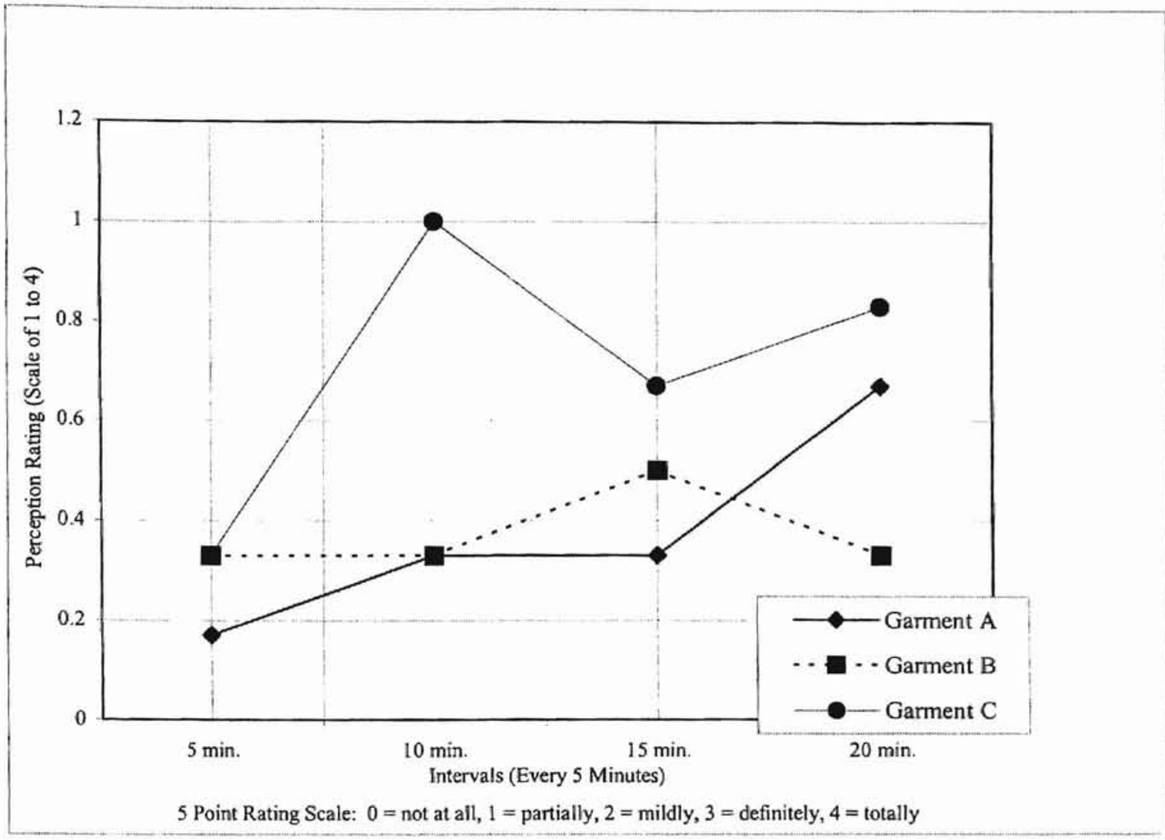
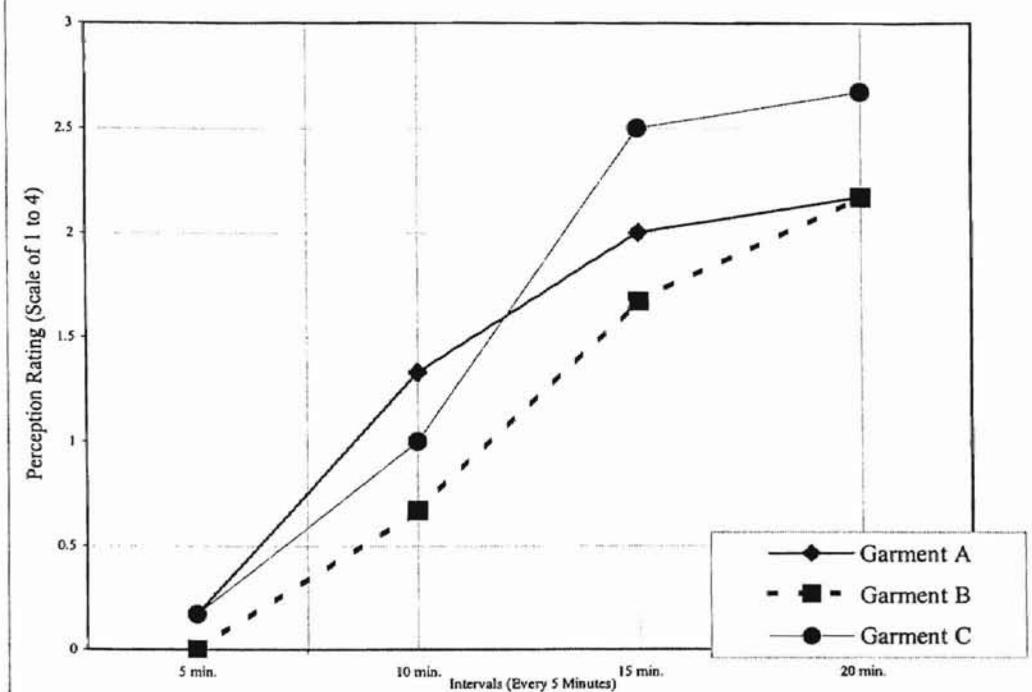


Figure 19. Perception Rating of Itchy



5 Point Rating Scale: 0 = not at all, 1 = partially, 2 = mildly, 3 = definitely, 4 = totally

Figure 20. Perception Rating of Hot

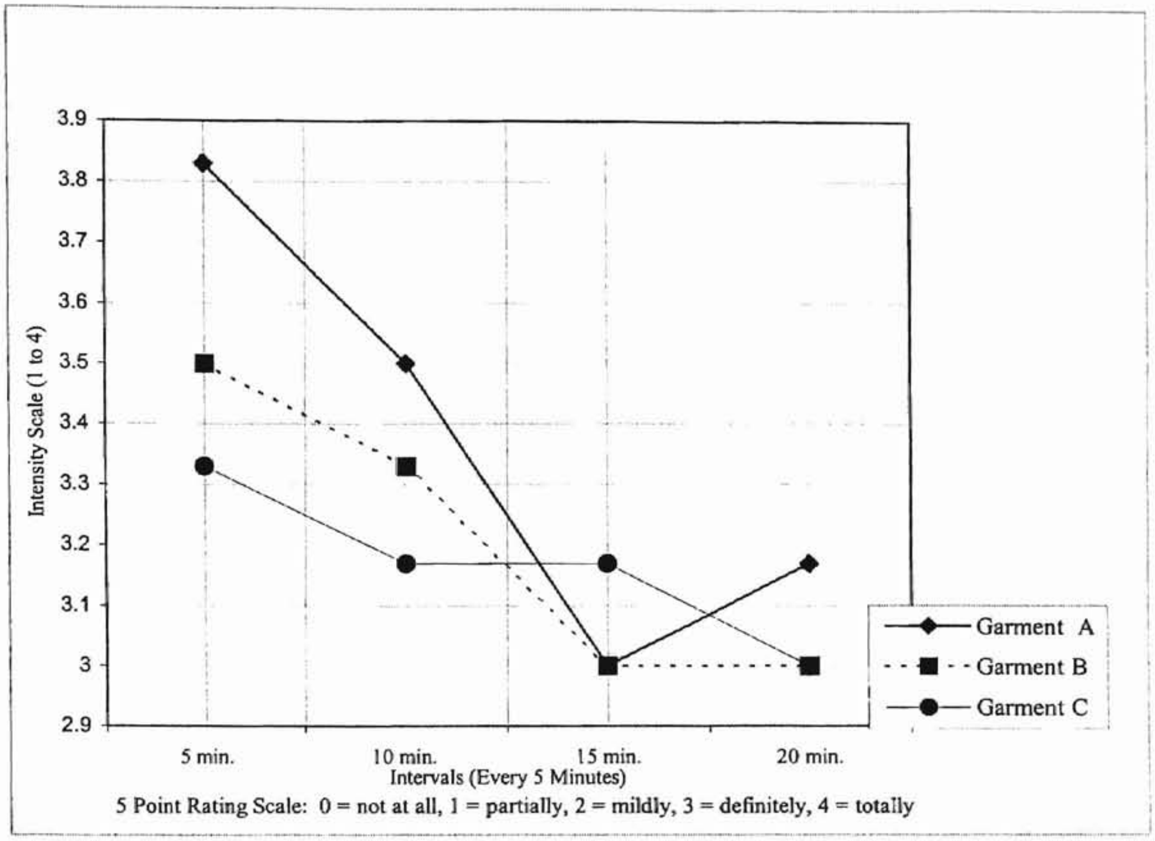


Figure 21. Perception Rating of Smooth

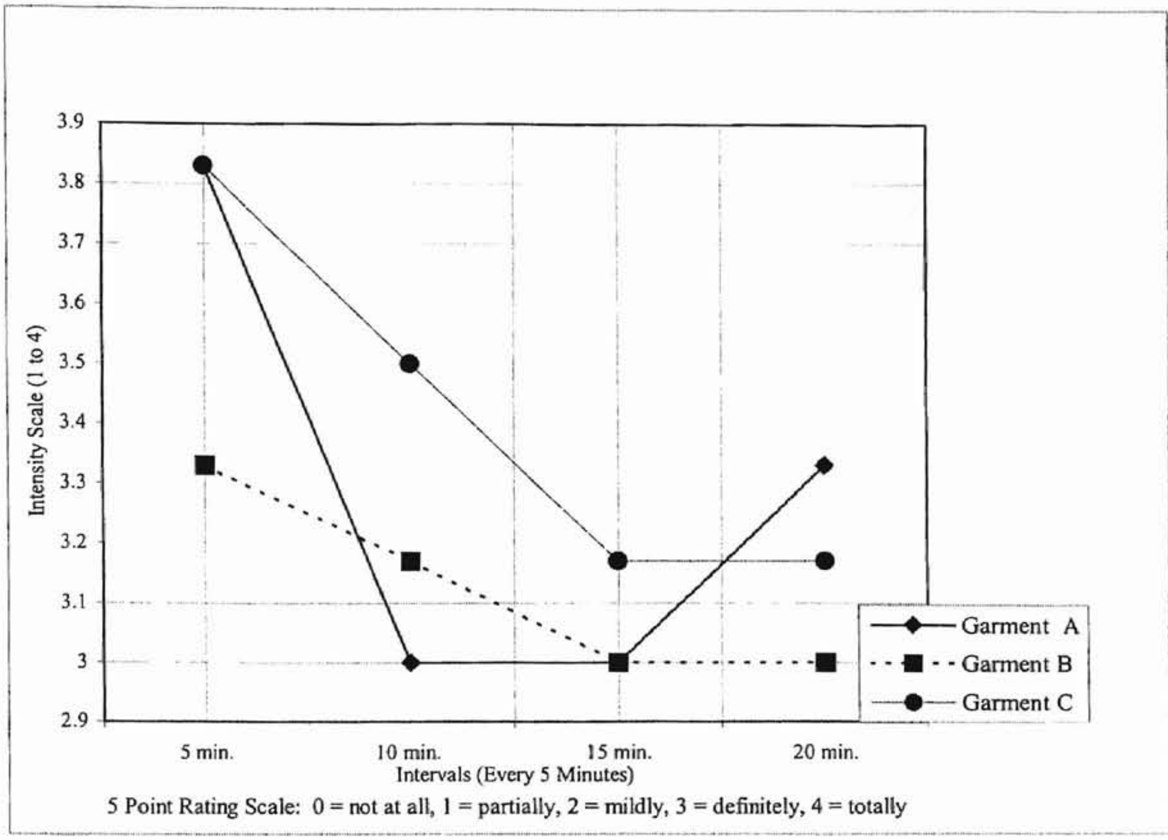


Figure 22. Perception Rating of Soft

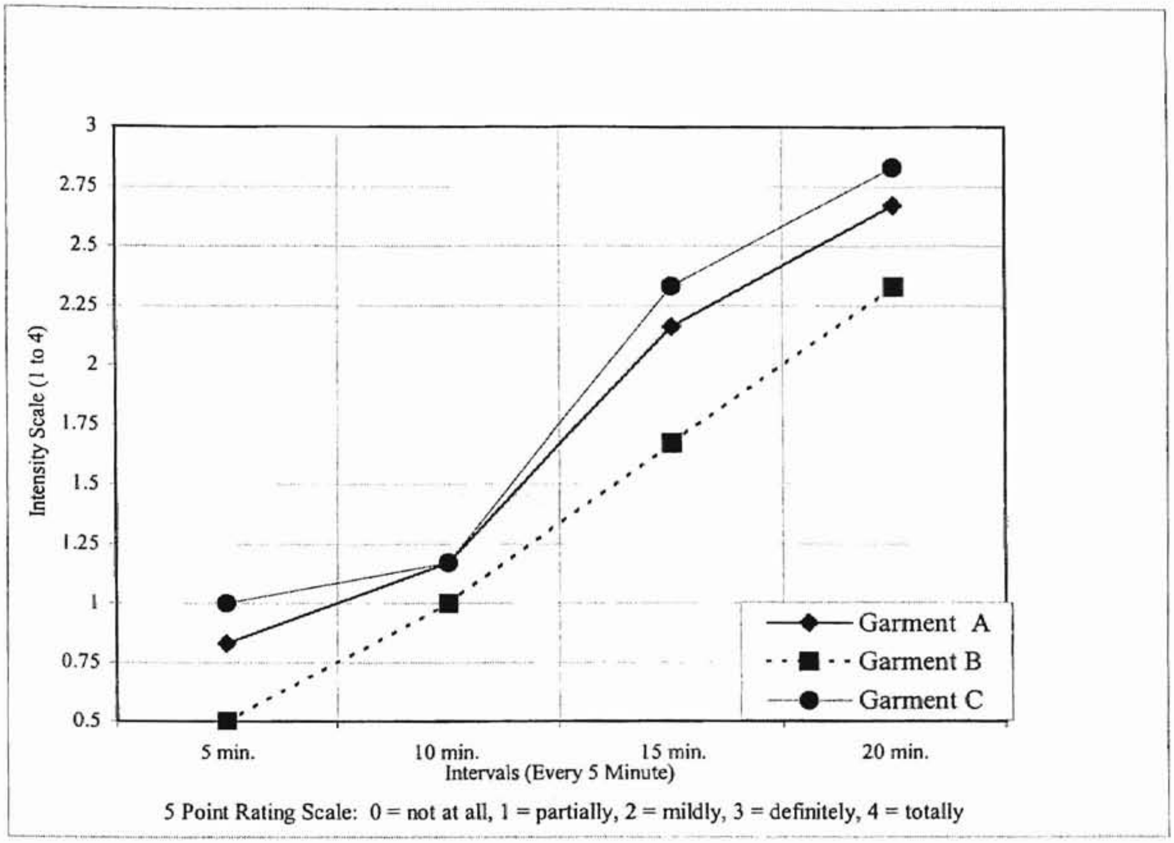


Figure 23. Perception Rating of Warm

VITA 2

Cathy Lynn Starr

Candidate for the Degree of

Master of Science

Thesis: EVALUATION OF A PROTOTYPE SPORTS BRA

Major Field: Design, Housing and Merchandising

Biographical:

Professional Experience: Graduate Teaching Assistant, Graduate Research Assistant, and Undergraduate Research Assistant, Department of Design, Housing and Merchandising, Oklahoma State University, Stillwater, Oklahoma.

Education: Received Bachelor of Science in Apparel Design from Oklahoma State University, Stillwater, Oklahoma, May, 1998; completed requirements for the Master of Science Degree in Design, Housing and Merchandising, Oklahoma State University, Stillwater, Oklahoma, in July, 2002.

Honors: NASA Oklahoma Space Grant Consortium Fellowship. Academic year 1999-2000. Phi Kappa Phi and Seniors of Excellence. Academic year 1997-1998.