AN ABSTRACT OF THE THESIS OF

LaJean Lawson for the degree of Doctor of Philosophy in Education presented on July 26, 1991.

Title: Chest/Breast Protectors for Female Athletes: Cushioning Properties and Effect on Selected Physiological and Performance Variables

Redacted for Privacy

Abstract approved: ___________

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Female participation in high-contact sports has increased dramatically in the past two decades, raising concern regarding injury to the female breast and the need for protective equipment. While the use of chest/breast protectors by women is advocated, little is known of their efficacy and effect on athletic performance. The purpose of this study was to determine the effects of chest/breast protector use on measures of performance and comfort, and to determine the mechanical response of the protectors to applied impacts.

The four chest/breast protectors selected for study included rigid polyethylene and flexible closed-cell foam styles. To evaluate physiological and comfort differences among the control (no protector) condition and the protectors, female subjects completed a submaximal treadmill running protocol, during which metabolic, skin temperature and perceived comfort data were collected. To evaluate effects on general agility, subjects completed a timed agility test. To assess cushioning properties, the vertical acceleration-time and force-displacement histories of a projectile during surface contact with each protector were analyzed using a drop test method. Analysis of variance methods were used to compare metabolic, temperature, comfort, agility, and energy absorption variables. Graphic presentations accompanied by qualitative interpretation of data across the time history of the impacts were used to describe cushioning properties of the protectors.

The chest/breast protectors in this study did not significantly increase oxygen consumption for submaximal treadmill running. Some but not all protectors produced significantly higher skin temperatures than the no-protector condition. Greater temperatures and temperature differentials between the skin and exterior equipment surface were associated with multiple plastic/fabric layers and closed-cell foam construction. No protectors produced significantly higher ratings of thermal sensation or perceived skin wettedness than the control condition. Two protectors were assessed as similar to the control condition on general comfort sensation while two were deemed to be significantly less comfortable. There was no decrease in general agility associated with protector wear. The closed cell foam protector generally showed better shock attenuation characteristics, while the rigid protectors generally demonstrated superior shock absorption. Relationships with regard to cushioning properties changed in response to systematic variation of missile mass and drop height.

Chest/Breast Protectors for Female Athletes: Cushioning Properties and Effect on Selected Physiological and Performance Variables

by

LaJean Lawson

A THESIS

Submitted to

Oregon State University

In Partial Fulfillment
of the Requirements
for the Degree of

Doctor of Philosophy

Completed July 26, 1991

Commencement June 1992

APPROVED:

Redacted for Privacy

Associate Professor of Exercise and Sport Science in charge of major

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Acknowledgement

As one goes through the process of planning, executing and putting closure on a thesis, it becomes apparent that the ultimate responsibility for finishing successfully rests heavily and completely on the student--if you don't just do it, it won't get done. However, it becomes equally apparent that the student's job is incredibly easier and more enjoyable when one has the privilege of working with a supportive and thought-provoking committee who treats the student as a peer. Such a group has been my good fortune and my inspiration. My sincerest thanks to you, Dr. Clarence Calder, Dr. Leslie Davis-Burns, Dr. Tom Grigsby, Dr. Gerald Smith, Dr. Anthony Wilcox, and Dr. Howard Wilson.

Special recognition is due my major professor, Dr. Anthony Wilcox, for his encouragement and help in tackling a research question in an area of study where little previous work has been done. His capacity to model and inspire good scholarship, his facility to promote critical thinking and evaluation of one's work, and his positive and affirming manner of offering criticism are exemplary of what one seeks in a mentor. The assistance of Dr. Clarence Calder and Dr. Gerald Smith in designing and implementing the impact testing and in analyzing the results was invaluable. I am grateful to Dr. Leslie Davis-Burns and Dr. Tom Grigsby not only for the inspiration and professional examples they have provided in the classroom, but for their suggestions and encouragement with regard to this thesis.

The data for this thesis could not have been collected without the assistance of Sharyl Peck-Whippo, Chris Quinn, and Lauri Zittel. Their dedication, and skill, coupled with their enthusiasm and wit, made the long hours in the lab enjoyable as well as productive. Also, I'd like to thank my ten subjects for their conscientious participation in this project.

I am certain that few investigators have the chance to work with a group of women so willing to help and who possess such a collective sense of good humor!

Recognition is also due the manufacturers of the protectors who donated their products and expertise to this project, with special thanks to JBI, Inc.

Finally and most importantly, the love and support of my family has helped ensure my success and sanity through my entire doctoral program. Jim, your total faith in me, your unconditional support for any dream I wish to pursue, and your enthusiasm for living life to the fullest are my joy and my great strength. My daughter, Kate, who was simultaneously conceived, incubated, and delivered along with this thesis, provided an incredibly wonderful reality check during the times when the thesis work seemed overwhelmingly and unrealistically important.

Oh yes, one more thing. Because I promised to do so during an uncharacteristically weak moment, I would like to publicly acknowledge that "Dr." Sharyl Peck-Whippo holds the world record for the "modified" McCloy agility course, with a time of 18.5 seconds, achieved while wearing the JBI protector.

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CHEST/BREAST PROTECTORS FOR FEMALE ATHLETES: CUSHIONING PROPERTIES AND EFFECT ON SELECTED PHYSIOLOGICAL AND PERFORMANCE VARIABLES

Chapter 1

INTRODUCTION

Historically, humans have used clothing as a means of adaptation and survival in many types of hostile environments (Renbourne, 1960). Today, modern contact sports constitute one such environment. Whereas a great deal of research has been devoted to the development of clothing and equipment to protect humans from environmental thermal and chemical stress, much less emphasis has been placed on apparel which protects from collision and impact (Watkins, 1977).

Injury in sport has sometimes been referred to as an occupational hazard because it is often part of an athlete's job to create physical contact with other participants and equipment (Garrick, 1972). Many athletes seem willing to accept whatever physical consequences, even those of a terminal nature, that may be associated with seeking a high level of performance (Hayes, 1974). Typical risk-taking behaviors include training to the point of developing overuse injuries, using anabolic steroids regardless of the physiological and legal risks, and dispensing with the use of protective equipment for fear it might interfere with performance.

These attitudes and behaviors have undoubtedly contributed to the lack of objective research on sports injuries and the effectiveness of protective equipment (Morehouse, 1986). According to Webster (1964), in the field of recreational sports there are probably more injuries occurring with less known about them and too little being done to minimize them than in any other area of activity. Haddon (1966) further suggests that,

> "We know more about the short- and long-term effects of smoking or of maternal rubella than we do about the beneficial and injurious effects of recreational activity, even though these [sports] occupy the time of millions of adults and children" [p. 885].

Increased female participation in contact sports and a more intense level of play in "noncontact" sports have raised concern regarding the potential for injury to the female breast and reproductive organs and the consequent need for protective equipment. Despite the paucity of epidemiological data regarding the incidence and severity of sport-related breast injury, sportsmedicine professionals who observe and treat injured female athletes routinely urge that breast protection be worn by females engaging in contact sports (Bayne, 1968; Gehlsen & Stoner, 1987; Haycock, 1978; Haycock, Shierman & Gillette, 1978; Klafs & Lyon, 1978; Thomas, 1974). The location and anatomical characteristics of the breast and the impact forces encountered in contact sports suggest that the potential for breast discomfort and injury is significant, and that a player wishing to lower that potential without sacrificing aggressiveness during play will seek breast protection.

Yet, when a female athlete attempts to procure a chest/breast protector, she is faced with a limited number of choices in the marketplace. Existing products often are not anthropometrically correct for the female anatomy, are not ergonomically efficient, are designed based on tradition rather than research, and have not been tested for efficacy of protection against impact. A player who resists protective equipment for fear that performance will be diminished is not likely to accept products that are ill-fitting, heavy, uncomfortable, and not proven to provide adequate protection.

The existing body of research on protective equipment for sports does not include studies concerning breast protection for females. A comprehensive examination of existing chest/breast protectors and their effect on performance and comfort is an important and much-needed step in the direction of safer contact sports participation for women.

Statement of the Purpose

The purpose of this study was to determine the effects of wearing selected chest/breast protectors on measures of performance and comfort, and to determine the mechanical response of the selected protectors to applied impacts. Physiological, psychological and physical variables related to performance and comfort were selected for analysis. Physiological variables including oxygen consumption and local skin temperature were evaluated during exercise both during the wearing of each specific protector and in a control (no protector) condition. In addition, the effect of protector wear on overall agility and on local thermal sensation, local wettedness sensation and general comfort sensation was examined. The acceleration-time and force-displacement histories of the vertical acceleration of a projectile during surface contact with a test manikin fitted with each protector were analyzed using a drop test methodology.

Hypotheses

The following hypotheses describe the relationships that were expected to be observed in this study:

1. Protector wear was not expected to significantly increase oxygen consumption during exercise.
2. Protector wear was expected to significantly increase local skin temperature values beneath the protectors.
3. It was expected that protector wear would result in higher ratings of local thermal sensation and local skin wettedness, and in lower ratings of general comfort sensation.
4. The effect of protector wear on general agility was expected to vary among the protectors tested.
5. It was expected that the protectors would vary in cushioning characteristics as assessed by drop testing.

Scope of the Study

Subjects for the study were ten conditioned female athletes who were capable of completing the maximal, submaximal, and agility test protocols. With the exception of the impact testing, data were collected within a two-week framework for each subject in the Human Performance and Biomechanics Laboratories in the Department of Exercise and Sport Science at Oregon State University. Impact testing was performed in the Biomechanics Laboratory using a humanoid manikin rather than human subjects.

Significance of the Study

This comprehensive examination of existing chest/breast protectors and their effect on performance and comfort is an important and necessary step in the direction of safer contact sports participation for women. The empirical information gained will not only assist manufacturers in designing and developing better products, but can help lessen athletes' resistance to utilizing protective equipment. Acceptance of protective equipment by the athlete may be enhanced with the demonstration that products exist which do not significantly impair performance or comfort and which indeed may improve long-term sport success through effective reduction of injury and discomfort.

Limitations of the Study

It must be recognized that the experiment took place under environmental conditions that represent only one possible combination of many sets of conditions normally occurring during contact sport participation. Therefore, the application of findings may be limited to indoor activities where temperature, relative humidity, and ventilation are similar to the test conditions. It must also be recognized that while environmental conditions were controlled across all test conditions to the best extent within the available facilities, there were minor daily fluctuations in ambient conditions that could have affected physiological and psychological variables.

Whereas use of the treadmill to establish and control workload is a valid and reliable means of estimating the aerobic demand of submaximal running, the athlete in contact sports is not limited to a normal, regular gait. Movements are more frequently characterized by abrupt direction changes, rapid accelerations and decelerations, and non-cyclical changes in body position. Changes in direction, pace, and position require additional energy to overcome inertia (Bailey & McDermott, 1952). This implies that the contact sport athlete is not using energy at a constant, submaximal rate. Thus, application of the findings of this research may not extend to non-steady state activities.

The subjects were selected to be an anthropometrically modal group representative of the population of women in contact sports. However, because the variable of physical build can affect the wear and evaluation of a garment (Morris, Schutz & Prato, 1972), application of the findings may not extend to women who do not match the anthropometric profile of the subjects in this study.

It has been shown that during steady-state submaximal exercise at constant air temperature, feelings of discomfort may be reduced in more fit individuals (Gagge, Stolwijk & Saltin, 1969). Hence, differences in fitness levels among subjects may have affected individual sensitivity to feelings of discomfort and subsequent evaluations of the chest/breast protectors. In addition, descriptor adjectives used in perceived comfort scales may have had different meanings for different subjects, so that the same descriptor may have represented different physiological states for different subjects.

Whereas the attempt was made to select chest/breast protectors for this study that are most representative of the major styles of equipment currently available to women, application of the findings of this research may not extend to other styles and brands of chest/breast protectors.

Because of the potential risk of injury to biological tissues, the impact testing in this study was necessarily performed using a test manikin. The mechanical characteristics and response of the manikin to impact may differ from those of the biological tissues of the human body. Thus the findings may be interpreted only as a comparative evaluation of the chest/breast protectors under the specific research conditions, and no significance can be placed on any obtained values with respect to human injury tolerance.

Whereas off-the-body drop tests such as the impact test methodology used in this study can be highly reliable and provide useful comparative information about cushioning properties, Nigg (1990) cautions that they cannot be used to predict forces acting on internal body structures, only to quantify external "input" forces. Hence, again no significance can be placed on obtained values with respect to human tolerance.

Delimitations

This study was delimited to 10 conditioned female subjects ranging in age from 27 to 41 years, who wore a conventional bra size of 34 A and B, 36 A and B, and 36 C. None of the subjects possessed orthopedic impairments that would have affected their performance of metabolic or agility tests. The submaximal exercise task used to derive physiological and perceptual data was treadmill running.

Definition of Terms

Agility is "the physical ability that enables rapid and precise change of body position and direction" (Johnson & Nelson, 1986, p. 226).

Area elastic material is defined as a material, which when impacted, distributes the force over an area larger than the area of the projectile due to its stiffness.

Clothing as defined for this study, includes all body coverings from head to toe, including protective clothing such as body armor.

Comfort is "the sensation of contented well-being and the absence of unpleasant feelings" (Fuzek & Ammons, 1977, p. 121). In the narrower context of clothing,"it is a subjective response resulting from complex interactions of environmental conditions, fabric properties, garment fit, physiological factors, and the psychological state of the wearer" (Morris, Prato & White, 1984-85, p. 14).

Contact sports are defined, for the purposes of this study, as those sports involving low frequency, moderate force body contact (i.e., basketball) as well as sports involving high frequency, maximal force, calculated impacts (i.e., martial arts and football).

Cushioning is the term used to indicate the overall ability of a material to dampen or reduce the shock of an impact.

General Comfort Sensation is the subjective statement describing the overall feeling of pleasant or unpleasant body sensations.

Injury is commonly defined in epidemiological studies of athletic injuries as an occurence that results in the loss of one or more days of participation by the athlete.

Martial arts is a generic term representing any disciplined study of kicks, blocks, and punches for self-defense, sports, fitness, or combat. While fighting techniques primarily utilize various body parts, they may also include the use of weaponry.

Local Skin Wettedness Sensation is the subjective statement describing the feeling of moisture at specified anatomical locations during exercise.

Local Thermal Comfort Sensation is the subjective statement describing the feeling of heat at specified anatomical locations during exercise.

Point elastic material is defined as a material, which when impacted, is affected primarily in the area directly beneath the point of impact because of its relative softness.

Protective equipment is defined as "personal equipment designed to attenuate kinetic energy from physical contact or impact between individuals or between an individual and an object within the playing environment" (Morehouse, 1986, p. 392).

Shock Absorbency refers to the ability of a material to absorb the energy of an impact.

Shock Attenuation is defined as the ability of a material to reduce the magnitude of peak acceleration during an impact event.

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

Chapter 2

REVIEW OF THE LITERATURE

Historically, the development of protective sports equipment has paralleled the evolution of game rules and techniques. As sports techniques and strategies have become more technical and sophisticated, injury risk factors have generally increased, creating the need for the development of appropriate clothing and protective equipment to promote safety and efficient performance (Morehouse, 1986; Reilly & Lees, 1984). However, the majority of sports are highly traditional when making changes in rules or equipment. In most cases, product design has been based on prior tradition, trial and error, fashion considerations, and subjective input of professional athletes rather than research, testing, and consensus industry standards (Goldman, 1981; Hayes, 1974; Morehouse, 1986). The majority of research, when it has been conducted, has involved equipment designed for use in sports such as football, where there is significant risk of serious injury, impairment, or death due to cerebral and spinal injuries, and where the financial liability to the equipment manufacturer could be great if the product were to fail during use. Problems of discomfort and moderate injury due to sports participation have not attracted the same attention. Technological progress across the sports equipment industry is hampered because most equipment research is done in-house by the manufacturer, and test methods and results remain proprietary to protect the company's financial and legal interests (C. Morehouse, personal communication, September 6,1989).

A rigorous search of public domain literature leaves the impression that protective body padding and its effect on sports performance have virtually escaped scientific scrutiny. In fact, not even one study directed specifically to the topic could be found. This dilemma prompted an investigation of a wide range of literature. Research from a number of related disciplines has been assembled to provide support for this study.

The following literature review addresses three major topics: 1) the problem of protecting the female breast in sport, 2) the effects of added weight and clothing on physiological, physical and psychological variables, and 3) the performance of sports bras and related shock absorbent sports equipment.

The Female Breast: A Case for Protection

Sports participation by women of all ages has increased dramatically in the past two decades. Several societal forces have driven this participation. Equal rights legislation, especially Title IX of the Federal Education Act, mandates equal access for males and females to educational facilities, including those for sport (Haycock, 1978; Haycock et al., 1978; Rose, 1981;Wilkerson, 1984). In practice, this means that schools from primary to collegiate levels must provide parity in sport opportunities to both genders. Not surprisingly, female participation in collegiate sports has increased 800% since Title IX was enacted (ESPN television broadcast, February 12, 1990). More women are now competing for physically rigorous jobs once open only to men, such as fire fighting and military combat. Women have discovered that participation and achievement in sports, which have been traditional sources of self-esteem and body image for males, can provide a powerful sense of satisfaction and self-efficacy (Micheli & LaChabrier, 1984).

Increased participation is evident not only in those sports traditionally played by women, such as softball, basketball, tennis and field hockey, but also in those sports once played primarily by males, such as football, soccer, ice hockey and martial arts (Birrer & Birrer, 1983; Micheli & LaChabrier, 1984). Female involvement in sports with a greater frequency and magnitude of contact forces has raised concern about the potential for and consequences of injury to the female breast and reproductive organs (Corbitt et al., 1975; Haycock et al., 1978).

Susceptibility of the Breast to Injury. While the incidence and prevalence of injury of a particular body part in various sports is often calculated from epidemiological data, information on injury to the breast as a result of sports participation is scarce. All national sports injury data clearinghouses were contacted by the researcher, and none tracked breast injury as an anatomical category. In Gillette's (1975) study of intercollegiate athletes, breast injury was listed as the least common athletic injury. When Hunter and Torgan (1982) examined injury records for women's intercollegiate sports at a major western university, they found that no breast injuries or pain had been reported to team physicians or trainers during the five years studied. There is some reason to believe that these figures do not represent the true incidence of sport-related breast trauma. According to Gehlsen and Stoner (1987), breast injury incidence is rarely reported in injury surveys because report forms do not list "breast" as a specific category, hence breast injuries are absorbed into the "miscellaneous" category. Compounding the problem is the reluctance of many females to report breast discomfort or injury for documentation or examination, particularly to male physicians and trainers (Haycock et al., 1978; O'Donoghue, 1976). In fact, when Haycock surveyed academic physical education departments and women's professional football teams, she found that of the approximately 16% of respondents reporting the occurrence of breast injury among their female athletes, most of the affirmative responses came from female coaches and trainers. Some male trainers in the study attributed the reluctance to report breast injuries to a fear of being labeled as a "baby" or of losing a scholarship or starting position on the team.

Despite the lack of epidemiological evidence, sportsmedicine professionals are nearly unanimous in their recommendation that the female breast be protected from impact in contact sports (Birrer, 1989; Haycock, 1978; Klafs & Lyon, 1978; O'Donoghue, 1976; Otis, 1988; Thomas, 1974; Wilkerson, 1984). The Committee on the Medical Aspects of Sports of the American Medical Association asserts that, "Since breast tissue is susceptible to injury in contact and noncontact sports, appropriate and adequate protection should be provided and its use encouraged" (Corbitt et al., 1975, p. 46). Klafs and Lyon (1978) suggest that protection is needed to guard against not only possible future trauma but also to protect existing injuries, as cumulative trauma is related to more serious complications. The use of padded and rigid plastic breast protectors is the intervention most commonly suggested. Birrer (1989) strongly advocates that all children in karate, regardless of gender, should wear mouthpieces, head gear and groin protectors, with the addition of breast protection for adolescent females.

This common concern for protection of the breast stems from a knowledge of breast anatomy as well as clinical experience in treating sports-related breast injuries. The mammary gland is prominently located on the anterior chest wall. It is not encapsulated in the conventional manner of many other glands but rather is held in place by fascial structures and the overlying skin (Gehlsen & Stoner, 1987; Haycock, 1988; Morehead, 1982). The breast is highly enervated and vascularized. Consequently, in the event of trauma the potential for debilitating pain and injury, such as laceration, contusion or hematoma, is significant. Shapiro (1983) reported that the team physician for a New York women's professional football team noted a high incidence of breast hematomas among players. While milder injuries such as contusion may require only ice packs, compressive dressings and analgesics as treatment, laceration additionally requires repair under sterile conditions. A hematoma caused by deep trauma or high-velocity impact may require evacuation and administration of antibiotics to prevent secondary complications of abscess or mastitis. Persistence of a fibrous nodule after evacuation may necessitate surgical removal (Haycock, 1988; Otis, 1988).

There is no evidence that single uncomplicated trauma such as that typically experienced in contact sports is associated with the development of breast malignancies (Gehlsen & Stoner, 1987; Haycock, 1978; Monkman, Orwoll & Ivins, 1974). In fact, athletic participation and its consequent health benefits may be associated with lower incidence of breast and reproductive tract cancers (Frisch et al., 1985; Haycock, 1978; Otis, 1988). However, repeated trauma to the breast resulting in contusions and hemorrhage may produce fat necrosis, which can be difficult to diagnostically differentiate from malignancy (Bayne, 1968; Klafs & Lyon, 1978).

Curiously, many sportsmedicine specialists who have described the nature and magnitude of torso injuries associated with sports-related impacts appear to have completely ignored the presence of the female breast on the chest wall. Trauma to the torso has been associated with injuries (bruise, contusion, abrasion, fracture, strain, sprain, laceration and rupture) to the skin, muscles, skeletal system, and viscera which lie inferior to the skeletal system (Allman & Ryan, 1974; Eichelberger, 1981; O'Donoghue, 1976; Stanish & Reardon, 1984). No mention is made of the existence of or the risk to the breast, which occupies a prominent and vulnerable position exterior to the ribs.

Sports-related impacts may be of particular concern to women with surgically augmented breasts. Blunt trauma to the breast can cause bleeding and hematoma within the vascularized capsule of fibrous tissue that forms around the implant, or rupture of the capsule. Implant rupture may also occur, necessitating surgical exploration, attempted retrieval of the dispersed silicone gel (which can escape into the axillary and abdominal areas), and replacement of the implant (Dellon, Cowley & Hoopes, 1980). The authors cite the sport-related case of a female who was struck on an augmented breast by a line drive baseball. The breast became painful and significantly swollen. Surgical exploration revealed the presence of an intracapsular hematoma which required evacuation. Although the implanted silicone gel-filled prosthesis was intact, it was replaced.

Forces and Injuries Encountered in Contact Sports. Recommendations that athletes use appropriate protection when engaging in contact sports are also based on a knowledge of the characteristics of a given sport, including the magnitude of forces that may be encountered during participation, and on the extent of injury associated with the sport. Biomechanists have sought to describe the kinematic and kinetic characteristics of a number of contact sports based on the nature of the equipment and the specific movement patterns involved. Epidemiologists have investigated the overall prevalence, nature and severity of injury within each sport.

Fencing. Kerwin and Challis (1985) examined slow and fast fencing foil lunging techniques using a nationally ranked female fencer as the subject. The fencer performed a series of alternating slow and fast lunges at an instrumented pendulum target. The time from initial target contact to peak impact force for both techniques was approximately 4 milliseconds, and the force dropped to a constant level of about 10% of the peak value in an additional 10 milliseconds. The magnitude of the first impact spike averaged 50 Newtons (N) for the slow lunge and 75 N for the fast lunge. Instantaneous peak values were approximately double, at 103 N for the slow lunge and 150 N for the fast lunge. Foil velocity ranged between 2.83 and 3.79 meters per second (m/s).

Football and soccer. No studies were found documenting the magnitude of forces encountered in women's football and soccer. Collins (1987) examined injuries in women's flag football and found the majority of injuries resulted from collisions with other players and objects. Torso injuries were not differentiated from the "other" category. Collins suggested that the low incidence of head and shoulder injuries among females "probably reflects a hesitancy to 'throw the body into the fray'" (p. 242). Keller, Noyes and Buncher (1987) observed that national and international female youth soccer players apparently sustain twice the number of injuries as male youth players. The number of injuries to the torso was not identified. The authors concluded that inadequate protective equipment contributes to the injury rate.

Ice hockey. "Ice hockey has been referred to as a violent sport played with clubs (hockey sticks), a bullet (puck), and knives (skates)" (Sim, Simonet, Melton & Lehn, 1987, p. 32). Sim and his colleagues used high-speed cinematography to estimate the velocities of the above-mentioned weapons during play. They found skating velocities of greater than 20 miles per hour (mph) for pee-wee players and velocities of 30 mph for senior-amateur players. During a fall, in which case the player was often about to strike the boards, goal or another player, sliding speeds of up to 15 mph were recorded. The processed rubber puck is 3 inches in diameter, 1 inch thick, and weighs 6 ounces. Velocities as high as 50 mph for young (12 to 14 years of age) players, 90 mph for senior recreational players and 120 mph for professional players were cinematographically documented. Relative angular velocity of the hockey stick during shooting ranged from 20 to 40 radians per second (rad/sec). Maximal impact force of a puck at the recorded terminal velocities approached 5,600 N.

While the large forces encountered in ice hockey suggest a great potential for trauma, the incidence of injury is lower than one might anticipate. Rielly (1982) has suggested that the widespread use of protective equipment along with the ability of players to mitigate force by sliding along the low-friction ice surface are responsible for the reduced incidence. Rielly also mentions skin infection caused by pathogenic bacterial growth on unsanitized protective equipment as the most common intrinsic injury associated with ice hockey.

Field hockey. The game is played with a wooden stick and a leather covered ball weighing between 5 and 6 ounces. The goalie, the only player to wear protective equipment other than shin and mouth guards, dresses similarly to her ice hockey counterpart with face mask, chest protector, thigh pads, substantial shin guards, and padded gloves (Rose, 1981). Rose examined women's field hockey injuries at a major university over a three year period and found 81 reported injuries. While 56 injuries were seen by a team physician, the majority were minor, such as ankle sprains. Sixteen percent, however, were major and were often associated with the hockey stick. These serious injuries included shoulder subluxation, cerebral concussion, second-degree cheek contusion, knee injury, and chest wall injury.

Lacrosse. While no biomechanical studies of lacrosse were found, Butler (1983) described the sport as an aerial game in which a wooden or aluminum shafted stick is used to propel a hard rubber ball through the air. In the women's game, the use of protective gear is sparse. Only the goalie wears chest protection, which is necessary as the chest is used to stop balls travelling as fast as 90 mph (Silloway, McLaughlin, Edlich & Edlich,1985).

The type of severe traumatic injuries typical of men's lacrosse are not as prevalent in the women's game due to rule differences dictating how the stick may be used. They do, however, occur. Because lacrosse involves aerial movement of both stick and ball, injuries to the head, face and hands are common, with contusions and lacerations being the most prevalent (Butler, 1983).

Martial arts. This is the contact sport that has perhaps been the focus of the most extensive biomechanical study. The term "martial arts" refers to a wide variety of systems of fighting techniques that utilize different body parts and occasionally weapons (Birrer & Halbrook, 1988). The more familiar styles include karate, full-contact karate, taekwondo, kick boxing, kendo, and judo. The novice martial artist often begins training with solo practice, moving on to kicking and striking objects, and eventually to sparring as his or her expertise increases. Sparring may be "prearranged" in which both partners move in a predefined pattern, or "free" in which partners extemporaneously administer blows. Sparring is categorized as "full-contact" in which punches and kicks are purposely landed and "non-contact" in which, theoretically, the blow culminates just short of hitting the target (Kurland, 1980). In taekwondo, for example, fighters may kick all parts of the body above the belt, including the head, and receive points for correctly and powerfully administered blows (Siana, Borum & Kryger, 1986). Achieving true "non-contact" assumes that players possess good body control, are technically skilled, never misjudge movement of the opponent, and do not get emotionally carried away in the effort to score points. In reality, "non-contact" sparring involves light to moderate contact (Kurland, 1980; Schwartz et al., 1986).

Various types of karate arm strikes and punches have been studied by biomechanists. Vos and Binkhorst (1966) used stroboscopic photography to examine the velocity and force of karate arm movements. They found velocities ranging from 46 to 51 km/h and forces used to break bricks ranging from 47 to 89 kg. In his analysis of a forward karate punch, Walker (1975) estimated the maximum momentum of a 7 kg (free mass) arm to be approximately 49 kg m/s. If contact time is 10 milliseconds or less and the fist comes to a complete stop during that time, the average impact force could be as great as 4900 N. Such a blow applied to the head could result in an acceleration of 89 *g*. In their study of karate chops intended to break pine boards, Cavanagh and Landa (1976) observed angular velocities at the elbow joint reaching 29.5 rad/sec. Blum (1977) found the peak velocity of a karate punch to be between 7 and 14 m/s. Using an estimated mass of 7 kg for the hand and arm, initial kinetic energy produced was calculated at between 171 and 687 J for the extremity alone, which is sufficient to break blocks of wood and concrete. Feld, McNair and Wilk (1979) reported peak velocities of 10 to 14 m/s and forces of more than 3000 N for the striking hand.

In his study of the impacts associated with certain karate kicks, Gray (1979) examined high speed film, accelerometer and load cell data. He reported that film-derived kick terminal velocities varied from 10 to 19 m/s, that the resultant acceleration of an instrumented dummy ranged from 19.5 to 29.6 *g*, and that the generated kick force as measured by the force transducer ranged from 2800 to 9850 N. Based on comparison with automobile chest impact data, Gray concluded that karate kicks can cause severe chest injury.

The epidemiology of martial arts injuries, both during training and competition, has been the focus of a number of investigations. Cantwell and King (1973) observed that injuries of serious concern in karate were trauma to the head, liver, spleen, heart and kidneys. In one of his earlier studies, McLatchie (1976) reported 80 injuries in the 285 karate contests examined, an injury rate of about one in every four contests. Nearly 10% of the injuries were severe enough to cause withdrawal from competition. In a later study of 70 competitors in full-contact knockdown karate contests, 53% were injured. Foot, shin and groin guards were the only pieces of protective equipment allowed. Injuries documented included nose lacerations, cerebral concussions, rib fractures, testicular trauma, and hematomas to various limbs (McLatchie, Davis & Caulley, 1980). Other injuries sustained during competition identified by McLatchie (1981) have included: cervical dislocation; visceral injuries including transient unconsciousness from solar plexus trauma; lung, liver, spleen and kidney rupture; traumatic pancreatitis; and testicular contusion. McLatchie concluded that, "It is not really surprising that karate injuries can be severe when one considers that the original intention of the martial art was to kill or maim an opponent " (p. 84).

Birrer, Birrer, Son and Stone (1981) suggested that taekwondo participants are especially susceptible to abdominal trauma because that anatomical region is part of the designated striking zone. They reported liver and spleen contusions, ruptured diaphragms, fractured xiphoids, and contused pericardia and myocardia.

Kurland (1980) followed 49 members of a university karate club for nearly 1,000 hours of practice. Injury rate for the group was 37 per 100 participants, with males reporting 18 injuries per 1,000 practice hours and females reporting 21 injuries per 1,000 practice hours. Injury often occurred when the offensive player misjudged the distance of the delivered blow or the defender moved unexpectedly into the technique. Kurland stated that the use of appropriate hand, foot and chest protectors, while perhaps awkward, could have prevented 72% of these injuries.

Birrer and Birrer (1983) observed and interviewed 49 males and 8 females during and after martial arts competition and training sessions. A total of 79 injuries were observed during three training sessions and three tournaments, of which 36.7% were reported and 63.3% were unreported by the athletes. The investigators attributed this withholding of information to feelings of invulnerability inherent in the philosophical bases of some martial arts styles, to confusion about how injury is defined, and to an elevated pain threshold common to martial arts practitioners. Kurland (1980) concurred that students are instructed to disregard pain and keep fighting, an attitude that "...may have been a good attribute on the battlefield, but ... not ... an enlightened viewpoint for this era of sportsmedicine" (p.85).

Siana et al. (1986) tracked the number of injuries requiring hospitalization at the 6th Taekwondo World Championship. The 15 injuries reported included fracture of the zygomatic bone with protrusion of the eyeball and double vision, dental and ulnar fracture, and contusion of the deltoid region. These injuries were sustained despite the use of mouthguards and protective body padding.

Birrer and Halbrook (1988) reported on a five year (1980-1984) national survey of martial arts injuries which used National Electronic Injury Surveillance System (NEISS) data. Of the injuries reported, 95% were mild to moderate in severity. Eighteen percent occurred in the trunk. The number and severity of injuries increased in "full contact" styles and in situations where protective gear was not utilized.

Zemper and Pieter (1989) investigated injury rates among athletes competing in the 1988 U.S. Olympic Taekwondo Team trials (Seniors) and the 1989 U.S. National Junior Taekwondo Championships (Juniors). For

Seniors, the injury rate for males was 40% higher for males than for females. Women tended to be injured more often during offensive kicking moves, and the men's injuries occurred most often as a result of (or in some cases, a lack of) defensive moves. Among the Juniors, the injury rates for boys and girls were very similar. The researchers concluded that the number of head injuries and fractures strongly recommends a "serious re-evaluation of the protective equipment used in taekwondo, and an exploration of possible rule changes to reduce the frequency and severity of these injuries" (p. 220).

Resistant Attitudes Toward Protective Equipment. Despite the magnitude of forces encountered in contact sports and their potential for moderate to serious injury, athletes frequently resist using protective gear unless it is mandated and absolutely required for competition. While fears that use of the equipment will impede performance are a major source of resistance, other factors have been suggested. Although epidemiological studies reach the opposite conclusion, the idea that protective equipment actually makes sports participation more dangerous does exist. For example, some schools of karate do not encourage use of protective gear because it supposedly does not help develop the discipline of accurately focusing one's blows to stop just short of the target, thus inviting undisciplined violence (Stricevic, Patel, Okazaki & Swain, 1983). Nathan (1989) objected to an article recommending the use of protective equipment by children in karate. His students are not allowed to wear or use protective gear because it purportedly adds additional length to the limb and can cause miscalculation of the landing of the blow and possible injury. In a further curious twist of logic, he stated that:

> The force of a properly timed and focussed punch or kick will not be absorbed by any current protective gear and consequently the possibility of damage to the opponent is magnified if protective gear is worn, because of the false sense of security that pads engender. (p. 5)

Micheli and Riseborough (1974) stated that protective equipment is "developed to a sophisticated and sometimes dangerous degree in

American football" (p. 94), suggesting that added protection invites more aggressive and injurious play.

Factors related to physical and psychological comfort can also deter acceptance of protective clothing and equipment. Renbourne (1960) complained of soldiers being more concerned with fashionability and sex appeal of combat clothing than its functionality. If protective equipment such as armored vests and fire fighter's turnout gear are uncomfortable or seem to hinder movement, the likelihood that they will not be worn increases (Haisman, 1977; Huck, 1986). Many fruit growers exposed to pesticides have refused to wear currently available protective clothing because of its lack of thermal comfort (Branson, DeJonge & Monson, 1986).

The Effects of Added Weight and Clothing on Physiological and Physical Variables

Recognizing the potentially negative effects that heavy or occlusive clothing and gear can have on health and activity, researchers have examined a number of related variables. The weight, size, design, fiber, fabric, permeability, and positioning on the body of clothing and equipment ensembles have been systematically varied in attempts to determine their effects on energy consumption, core temperature, overall and local skin temperature, sweat rate, skin wettedness, agility, and perceptions of comfort. A great deal of the work has taken the form of physical testing of textile materials off the body using standard laboratory tests and of evaluation of clothing ensembles on stationary copper "sweating" manikins or resting humans. The current trend, however, is toward active physiological trials in which subjects perform specific physical tasks under climatically controlled conditions, as data from tests using isolated fabric swatches and inert manikins often correlate poorly with those from studies conducted on fully clothed, exercising humans (Huck, 1986; Huck & McCullough, 1985; Goldman, 1981).

Metabolic Cost Associated With Added Weight and Clothing Ensemble Wear. Increased metabolic energy cost associated with the wearing of a particular ensemble during a physically demanding activity is of interest to physiologists and clothing scientists for at least two reasons. First, augmented energy expenditure can result in earlier fatigue and lowered capacity to perform a physical task, and second, increased metabolism results in metabolic heat production that must be dissipated if the body's core temperature is to remain at a biologically tolerable level.

Research has centered on two issues: the effect of the weight of the clothing or load, and the effect of any encumbrance due to the presence of the layers of clothing over the moving limbs. Several studies have addressed the problem of the weight and bulk of military combat clothing, body armor and carried gear. The metabolic stress imposed by heat-protective clothing for fire fighters and industrial workers exposed to high thermal loads has also been investigated. Goldman and Iampietro (1962) of the U. S. Army evaluated the energy cost of added loads of 10, 20, or 30 kg worn on a packboard at various increasing levels of treadmill speed and grade, and found that energy cost per unit weight was fairly constant regardless of whether the weight was of the body or of the load. Givoni and Goldman (1971) devised formulas based on experimental studies that could be used to predict how much the metabolic rate would rise with the addition of external loads up to 30 kg. The formula for metabolic cost of load carrying while walking was:

$$M = \eta (W + L) [2.3 + 0.32 (V - 2.5)^{1.65} + G (0.2 + 0.07 (V - 2.5))]$$

where

M = metabolic rate, kcal/hr

η = terrain factor, defined as 1 for treadmill walking

W = body weight, kg

L = external load, kg

V = walking speed, km/hr

G = slope (grade), %.

A slight correction was necessary for predicting the metabolic cost of running with and without external loads:

$$M_{running} = [M_{walking} + 0.47 (900 - M_{walking})] (1 + G/100)$$

where

$M_{walking}$ = the predicted M for walking at the same speed, kcal/hr

G = slope (grade), %.

Givoni and Goldman's findings suggest that external loads of the magnitude presented by chest/breast protectors, which represent an average added load of less than 1/2 of 1% of body weight, should have negligible effect on oxygen consumption.

Further investigation by Soule and Goldman (1969) revealed that while carrying added weight (4 to 14 kg) on the hands or head demanded little increase in energy cost over equivalent increases in body weight, addition of the weight to the feet resulted in an increase in energy cost approximately six times that of equivalent body weight. This finding suggests that addition of a very light load to the torso (close to the body's center of gravity) in the form of a breast protector would not likely produce significant increases in energy demand.

In perhaps the most classic study of the effect of heavy, thick clothing on performance, Teitlebaum and Goldman (1972) attempted to determine if there was an increased metabolic cost associated with wearing multiple clothing layers beyond that due simply to its added weight. In addition to standard military boots and fatigue uniform, subjects wore either a five-layer arctic clothing system weighing 11.19 kg, or carried an equivalent amount of weight in lead shot in ammunition pouches on a waist belt while walking on a treadmill. The energy cost of wearing the multiple layer clothing system was significantly ($p < 0.001$) greater than that of wearing the weighted belt. The approximately 16% increase in energy cost of the clothing system over the weighted belt was much greater than could be attributed simply to a shift of some of the clothing system's weight further out on the limbs. The authors attributed the increase to either frictional resistance between the clothing layers during activity or to a "hobbling" effect in which bulky clothing interferes with joint movement.

In Hollies, Fourt, Arnold and Custer's (1973) study of firefighter's turnout coats, subjects performed a protocol of raising and lowering the arms with and without various styles of turnout coats. The wearing of a coat was associated with a higher metabolic cost, with heavier coats demanding more energy than lighter coats. Abeles, Bruno, DelVecchio and Himel (1978) found that the wearing of full turnout clothing ensembles produced metabolic increases of 20% to 85% above baseline, depending on the design of the ensemble. In Eissing's (1984) comparison of light work clothing, polyurethane and Goretex® raingear, and insulated heat protective clothing, he found increases in oxygen consumption for the heat-protective clothing ranging from 5% to 12% above the light work clothing baseline, with the heavier garments producing the greater increase.

In two different studies comparing three types of warm-up suits varying in permeability and moisture transport characteristics, neither Gonzalez and Cena (1985) nor Morris, Prato, Chadwick and Bernauer (1985) found any significant differences among the ensembles in the metabolic cost associated with the wearing of a particular suit.

Local Skin Temperature Values Associated With Clothing Ensemble Wear. When clothing or protective equipment is donned, an immediate alteration is imposed on the thermal microclimate surrounding the body. Clothing layers impede all normal means of heat transfer--radiation, conduction, convection, and evaporation--and the movement of moisture (Clark, McArthur, & Monteith, 1981; Fonseca, 1970; Gonzalez, 1987; Hardy, Ballou, & Wetmore, 1953). This characteristic of clothing is of particular concern during strenuous exercise, a condition of high energy production. Unfortunately, only about 20% of the energy thus produced can be used for mechanical work; the remaining 80% in the form of heat creates an internal thermal load whose production rate can increase to 20 times the basal level, challenging the body's thermoregulatory capacity (Gonzalez, 1981).

Because of clothing's important role in controlling the temperature and comfort of the body's near environment, many researchers have investigated the influence of various fibers, fabrics, and designs on body temperature. Much of the previous research has examined the effect of permeable fabric layers and ensembles, or that of impermeable ensembles that envelope most of the body's surface (Abeles et al., 1978; Belyavin, Gibson, Anton, & Truswell, 1979; Branson et al., 1986; Duncan, Gardner, & Barnard, 1979; Falls & Humphrey, 1976; Fonseca, 1970; Gagge et al., 1969; Holmér, 1985; Huck, 1986; Livingstone, Reed, Nolan, & Cattroll, 1988; Martin & Goldman, 1972; McIntyre & Gonzalez, 1976; Reischl & Stransky, 1980; Tokura & Midorikawa-Tsurutani, 1985; Vokac, Køpke, & Keül, 1972, 1976). A number of these studies have been conducted under extreme environmental conditions of both hot and cold. Body core temperature and average skin temperature of the whole body have often been the quantities of interest in these investigations. The elevations in body core temperature which can occur as a result of heavy physical exertion in hot environments or while wearing impermeable clothing ensembles have been of particular concern, as the physiological stress thus induced can lead to heat exhaustion and, in the extreme case, failure of the body's homeostatic temperature regulation mechanisms (Falls & Humphrey, 1976; Huck, 1986).

For chest/breast protectors, however, the thermal quantities of interest are local measures of temperature at the skin's surface in the microclimate of the protector, which covers a relatively small area of the body and whose outer stratum is essentially impermeable. Relatively few studies have investigated local comfort values in moderate environmental conditions. The problem resulting from elevations of skin temperature beneath the protector is not one of physiological heat stress, but rather is associated with sensations of discomfort. If discomfort sensations are strong, a person may resist wearing the protective equipment (Haisman, 1977).

While a person's average skin temperature may fall into the "comfortable" range, localized sensations which vary widely from the comfortable average may be a source of discomfort. Fanger (1970) cites the classic example of the man with one foot in a bucket of ice water and the other in a bucket of scalding hot water, whose average skin temperature indicates thermal neutrality but who obviously experiences severe discomfort. Elevated local skin temperature also influences comfort in that, while of secondary importance relative to core and average skin temperatures, it has been linked to increased local sweating rate (Bullard, Banerjee, Chen, Elizondo, & MacIntyre, 1970; Gonzalez, 1981). Nadel, Bullard and Stolwijk's (1971) research suggests that elevated local temperatures act physiochemically at the neuroglandular junction to accelerate the cellular reaction rate, while Ogawa (1970) theorizes that the higher temperatures increase the sensitivity of receptor mechanisms to specific stimuli in sweat gland cells. Local heat and moisture are also related in that sweat vapor condensation occurring on the inner face of a multi-layered ensemble will cause a release of latent heat at that point, resulting in a higher local temperature (Gonzalez, 1987).

Recognizing the importance of regional as well as average values of temperature to comfort, some researchers have looked closely at local thermal values and changes related to clothing wear. In tests using half-garments in which one side consisted of permeable nylon and the other of impermeable coated nylon, Andreen, Gibson and Wetmore (1953) were able to create relatively large temperature differentials between the two sides of the body with higher temperatures associated with the impermeable fabric. Pontrelli (1977) compared acrylic with wool or cotton socks worn inside athletic shoes on the two feet of each subject. No significant differences were found between fiber types in maximum foot temperature or in temperature increase after fifteen minutes. Subjects wearing protective firefighter gear with additional insulative batting in the chest area experienced local chest temperatures ranging from 29.1°C at an exercise load of 10% of V_{O2max} to 38°C at 70% of V_{O2max} (Reischl & Stransky, 1980). In contrast, while wearing non-insulated control clothing, subjects' chest temperatures ranged from 29.0°C to 29.4°C for the same workloads. Nishi (1981) examined convective heat exchange, one mechanism by which heat may be dissipated from the body's surface. For subjects exercising on a treadmill, the lowest local convective heat transfer coefficients (h_c) in normal ambient air conditions were found on the back and chest, 4.3 and 4.5 respectively, compared to 15.4 for the hands and 14.4 for the legs.

In Laing and Ingham's (1984-85a) examination of five protective work coveralls varying only in fabric content and structure (none were totally impermeable), no significant differences in local skin temperature were found among the garments, but differences in skin temperature among the three body sites (trunk, upper arm, and upper leg) were significant. Gonzalez and Cena (1985) compared three clothing ensembles: a 60% polyester/40% cotton tracksuit worn over a long-sleeved 100% cotton sweat shirt (TS), the same ensemble with a Goretex® parka substituted for the jacket of the track suit (GOR), and the TS ensemble with an impermeable polyethylene overgarment worn over it (POG). Air movement was varied from still to 0.4 m/s to 2 m/s. Experiments with the highly permeable TS ensemble resulted in a significant lowering of chest and back skin temperature as air movement increased. While the GOR ensemble chest and back skin temperatures were lower than those of the POG ensemble, no significant lowering of temperature occurred with either ensemble as a result of increased air movement.

Branson et al. (1986) compared two fabrications of pesticide protective clothing prototypes with the cotton jeans and chambray shirt typically worn by agricultural workers for pesticide application. One prototype fabric was Gore-tex®, a multi-layer fabric utilizing a thin film of microporous polytetrafluorethylene with moisture transport capabilities. The other was Tyvek®, an impermeable, spun-bonded 100% olefin fabric. Three design variations allowing varying degrees of adjustability for ventilation and fit were constructed in each fabric type. Regardless of design variation worn, the ensembles constructed of the Tyvek® fabric produced higher local chest, arm, and leg temperatures than did the cotton and Gore-tex® ensembles. Local skin temperatures for the cotton and Gore-tex® ensembles were very similar. Nielsen and Endrusick (1990) examined 100% polypropylene underwear manufactured in five different knit structures (1-by-1 rib, fleece, fishnet, interlock, and double-layer rib) to determine the physiological effect of fabric structure. Wearing the underwear as the inner layer of a standard battle dress ensemble, subjects completed an exercise/rest/exercise/rest protocol in a cold (5°C) environment. On the chest, significant differences in local skin temperature occurred in the last part of the two exercise periods, with fleece and two-layer constructions producing higher values than the fishnet knit; no chest skin temperature differences were observed during the rest periods.

Local Skin Humidity Values Associated With Clothing Ensemble Wear. Moisture within the clothing microclimate is of concern because the presence and perception of skin wettedness has long been associated with sensations of unpleasantness and discomfort, particularly under resting conditions (Andreen et al., 1953; Cena & Clark, 1981; Fanger, 1973; Galbraith, Werden, Fahnestock, & Price, 1962; Hollies, 1971; Nishi &

Gagge, 1970; Slater, 1977; Tokura & Midorikawa-Tsurutani, 1985; Vokac et al., 1972). As little as 3 to 5% added moisture is sufficient to stimulate discomfort sensations (Scheurell, Spivak, & Hollies, 1985). During exercise, moisture on the skin's surface increases the magnitude of friction between fabric and the skin which can lead to irritation and chafing (Gwosdow, Stevens, Berglund, & Stolwijk, 1986). Clothing ensembles whose outer layer is nonpermeable are particularly problematic, as the resulting occlusion elevates skin wettedness levels with concomitant increases in dermal permeability to irritating substances, abrasion damage, and bacterial growth (Hatch, Maibach, & Markee, 1988; Hatch, Wilson, & Maibach, 1987; Zimmerer, Lawson, & Calvert, 1986). Of additional concern to the athlete is the after-exercise chill that can occur when exercise and sweating cease, but sweat trapped in the clothing continues to evaporate, resulting in undesirable cooling (Farnworth & Dolhan, 1985; Woodcock, 1962b).

As mentioned previously, the functions of skin temperature and skin humidity are interrelated. At ambient effective temperatures above skin temperature, the cooling mechanisms of conduction and convection cease to function, and the evaporation of sweat becomes the primary means of reducing body temperature through the carrying away of the latent heat of vaporization by the escaping vapor (Farnworth & Dolhan, 1985; Givoni & Belding, 1962). Higher local temperatures can stimulate the sweating response, and if sweat evaporation is relatively unimpeded, its cooling effect can in turn lower skin temperature (Gagge, 1981; Tokura & Midorikawa-Tsurutani, 1985).

According to Berglund, Cunningham, Höppe, Gwosdow, and Fobelets (1985), local skin wettedness is:

> A function of the local sweat secretion rate and its evaporation, which in turn is dependent on (1) the water vapor pressure gradient between the skin surface and ambient air, and (2) the vapor resistance of the intervening clothing and its associated boundary layer. (p. 1)

It is further defined as "the ratio of the observed evaporation rate...to the maximum possible evaporation rate" (Berglund, Gwosdow, Cunningham, & Fobelets, 1986, p. 64). Physiologically, the human organism is capable of producing sufficient sweat to dissipate all metabolic heat generated during sustained exercise, but in practice the clothing worn and the ambient relative humidity generally impede the cooling process (Woodcock, 1962a). In order for sweating to be 100% efficient, all sweat must undergo evaporation, and the process must take place at the surface of the skin rather than at the outer surface of some clothing layer (Ayling, 1986; Shapiro, Pandolf, & Goldman, 1982). Clothing, even if permeable, creates a barrier to evaporation, in that a great deal of sweat is absorbed into the clothing and only a small part is evaporated directly at the skin's surface (Nagata, 1978; Renbourne & Rees, 1972). Impermeable ensembles further impede the effectiveness of evaporative cooling (Gonzalez & Cena, 1985).

Several studies have specifically examined local skin humidity responses, particularly to various types of clothing ensembles. In Weiner's (1945) investigation of regional patterns of sweating, he determined that while the trunk represented about 39% of the total body surface area from which he collected his sweat samples, it accounted for about 50% of the total volume of sweat produced. This finding suggests that the trunk's average intensity of sweating is greater than that of other body parts. In tests of two different brassiere materials containing foams of varying air permeability, Standau, Rytter and Ziegler (1970) observed that the less permeable material produced a 14% greater relative humidity after 8 hours of normal wear. In comparing Gore-tex® rainwear with standard impermeable rainwear, Holmér and Elnàs (1981) found a significantly lower evaporative heat loss, higher vapor pressure gradient between the skin and the outer garment surface, higher evaporative resistance, and greater discomfort for the impermeable rainwear than for the Gore-tex®.

In Laing and Ingham's (1984-85a) study of protective workwear made from fabrics of varying air permeability, humidity of the clothing microclimate was measured on the medial side of the femur under conditions of high radiant heat, both during exercise and while at rest. No significant differences were found among garments in microclimate humidity at this anatomical site. Berglund and colleagues (1985) compared two-piece training suits constructed of 100% cotton, 100%

polyester, Gore-tex®, and polyurethane coated nylon using a 30 minute, 5 Met cycling bout followed by 60 minutes of rest in ambient conditions of 26°C temperature and 13°C dew point. The suits with higher vapor resistance (Gore-tex® and polyurethane) produced greater skin wettedness under all conditions and a slower decline in wettedness following cessation of exercise. In Gonzalez and Cena's (1985) previously described study of track suits of varying permeabilities, local skin wettedness for the chest increased significantly from the poly/cotton to the Gore-tex® to the polyethylene ensemble. Tokura and Midorikawa-Tsurutani (1985) examined differences in clothing microclimate humidity at frontal chest level between conventional polyester blouses and those treated with a hygroscopic finish to enhance moisture absorption. Subjects sat for 60 minutes in a warm (33°C), moderately humid (60% RH) environment. The researchers theorized that higher skin temperatures in the microclimate of the untreated blouse helped to stimulate greater sweating rates, with a consequent significant increase in humidity.

Hatch and her colleagues (1987) used a focused microwave probe and an evaporimeter for *in vivo* assessment of stratum corneaum water content and surface evaporation in response to various combinations of fabric and occlusion. Swatches of unoccluded triacetate and polyester placed on the skin did not cause significant changes in water content or evaporation as measured promptly upon removal. While covering the fabric swatches with a layer of plastic film did significantly increase both water content and evaporation, there were no differences due to the type of fabric under the film. In Nielsen and Endrusick's (1990) previously mentioned evaluation of the effect of knit structure on thermoregulatory responses during an exercise/rest/exercise/rest protocol, the fleece fabric induced significantly greater values of local skin wettedness on the chest than the other types of structures.

Perceived Thermal, Moisture and Comfort Sensations Associated With Clothing Ensemble Wear. The technical process of making judgments from perceptions is called psychological scaling and is widely applied to many types of commercial and scientific measurement, especially in the field of textiles and clothing (Hollies, 1977). These judgments can involve a single sensation, but more typically the perception involves a combination of several sensations. Some psychological scales have physical counterparts with which they may be highly correlated, a familiar example being Borg's perceived exertion scale (Borg & Noble, 1974). However, "the existence of a physical scale is not a requirement for making valuable, useful and precise psychological scaling measurements" (Hollies, 1977, p. 109).

Use of well-designed psychological scaling techniques allows maximum utilization of a human being's innate ability to perceive and evaluate complex phenomena without the interference of the instrumentation required for acquiring physical data (Hollies, 1977). Cena and Clark (1981) point out that,

> No matter how precise the measurement of the physical variables that specify the environment, the link between that environment and its rating as comfortable or uncomfortable is through questions put to people. (p. 280)

Andreen et al. (1953) assert that the comprehensive study of clothing comfort must include subjective opinion. DeMartino, Yoon and Buckley (1984) suggest that while objective measures can help to explain the results of subjective measures, they cannot replace perceptual data and that, in fact, the subjective evaluation should be the final answer. Optimally designed comfort research includes both types of analysis whenever possible.

Human perception analysis techniques have been applied to a wide variety of apparel garments worn in a range of microclimates at varying activity levels, and have been shown to provide a powerful tool and sound basis for comparing garment systems (Berglund et al., 1985, 1986; Branson et al., 1986; Gagge, Stolwijk and Hardy, 1967; Gagge et al., 1969; Hollies, 1977; Hollies, Custer, Morin & Howard, 1979; Holmér, 1985; Laing & Ingham, 1984-85b; McIntyre & Gonzalez, 1976; Morris et al., 1985; Nevins, Gonzalez, Nishi, & Gagge, 1975; Vokac et al., 1972, 1976). In some cases, perceptual data have been shown to be more sensitive in detecting significant differences in clothing comfort than objective measures, particularly in moderate environmental conditions where true physiological stress is minimal (Branson, Abusamra, Hoener & Rice, 1988). Indeed, because experimental conditions of environment and body activity must often be set at extreme levels in order to counteract the natural homeostatic tendencies of the body and produce differences in physiological data, subjective comfort assessment may be the most effective way of discriminating among clothing ensembles worn under more normal conditions (Laing & Ingham, 1984-85b).

According to Cabanac (1969), two elements are presumed in the formation of conscious sensations relating to comfort. The first is a discriminative element in which the subject verbally describes the physical characteristics of the stimulus, i.e., "hot," "cold," "very wet." The second is an affective element in which the subject expresses the pleasantness or unpleasantness of the perception, i.e., "somewhat comfortable," "intolerable." Local thermal sensation and humidity sensation estimates are discriminative in nature, whereas general comfort sensation estimates represent the affective component of the overall clothing sensation. Affective elements can be influenced by discriminative elements, as evidenced by Vokac et al.'s (1976) finding that comfort sensations reflected upward and downward deviations from neutral thermal sensation.

While earlier comfort research concentrated heavily on overall comfort sensation, more recent emphasis has been placed on patterning regional subjective and objective responses. Vokac et al. (1971, 1972) have shown that is it possible to localize and judge specific comfort sensations independently of sensations that may be occurring in other regions of the body.

Thermal sensation. Both ambient environmental parameters such as air temperature, speed and humidity, and individual variables such as clothing and activity level affect thermal sensation (McIntyre, 1981; McIntyre & Gonzalez, 1976). According to Latta (1977), thermal sensations created by apparel are derived from two physical characteristics of the materials: the bulk thermal properties of the clothing ensemble, and its air and moisture permeability. The affective sensation of thermal comfort correlates well with measured skin temperature, but the relationship varies with activity level (Fanger, 1970).

As exercise level (and consequently internal body temperature) increases, the mean skin temperature associated with a particular level of thermal comfort decreases (Gagge et al., 1969). Sweat secretion and thermal comfort sensation also correlate well, with the relationship again depending on activity level (Fanger, 1973).

In Gagge, Stolwijk and Saltin's (1969) study of thermal sensations during exercise at various ambient temperatures using shorts-clad subjects pedalling bicycle ergometers, temperature sensations across the range from "cool" to "hot" were primarily related to ambient air and skin temperatures, and appeared unrelated to rectal and muscle temperatures or metabolic rate. McIntyre and Gonzalez (1976) noted that subjects' ratings of overall thermal sensation were more sensitive to ambient temperature changes during rest than during exercise. Morris et al. (1985) found no significant differences in thermal sensation ratings for three fabrications of warm-up suits worn during exercise in both warm (32.6°C dry bulb) and cool (14.4°C dry bulb) environments. Subjects in Branson et al.'s (1986) previously described study of protective ensembles of varying permeability perceived themselves to be significantly hotter when wearing garments of highly impermeable Tyvek® fabric. This is not surprising, since local skin temperatures measured inside the ensembles were significantly higher for Tyvek® than for the other textiles. Laing and Ingham's (1984-85b) subjects did not rate the five fabrications of protective overalls significantly different on thermal sensation; however, there were also no significant differences among measured local skin temperatures for the five ensembles. Correlation coefficients for subjective vs. objective measures were low and non-significant.

Moisture sensation. Methods for the quantitative measurement of local skin wettedness, reviewed elsewhere by Graichen, Rascati and Gonzalez (1982), often present challenges to the researcher. Some apparatuses may be difficult to calibrate because of the nonlinear response of the humidity sensing materials used, may not yield frequent or continuous data, may intrinsically introduce error due to sampling configuration, or may be prohibitively expensive. Applying these methods to vigorously moving bodies introduces further complications. These difficulties have prompted the search for psychological scaling techniques for the evaluation of skin wettedness which can be easily and inexpensively administered. Several investigators have devised perceptual scales for the collection of subjective moisture data, and some have validated the scales by establishing their relationship to objective skin wettedness data.

Laing and Ingham (1984-85b), in their study of five types of protective workwear, found highly positive, highly significant correlations ($r = 0.82$, $p < .001$) between objective humidity data as monitored continuously by a Vaisala humidity probe and subjective local wettedness sensation as measured by a 3-point scale (dry--damp--dripping wet). In their evaluation of the comfort of three types of warm-up suits, Morris et al. (1985) observed a correlation of 0.985 between the amount of moisture remaining in undergarments after exercise and perceived wettedness ratings based on a 7-point scale ranging from "dry" to "very wet." In comparing garments of varying vapor resistances, Berglund et al. (1985) used dew point sensors to measure skin wettedness of subjects exercising at 5 Mets on bicycle ergometers. Correlations between the subjects' reported feelings of regional skin wettedness and the measured values were high ($r = 0.94$ at a higher air speed of 1.4 m/s; $r = 0.91$ at a lower air speed of 0.05 m/s). Berglund et al. (1985) also utilized a 7-point scale ranging from "dry" to "soaking wet" to evaluate perceptual responses.

<u>Comfort sensation</u>. The term "comfort" is generally understood to mean a condition of emotional and physical satisfaction, ease, and contentment with one's environment. In the field of clothing and textiles, it refers specifically to satisfaction with the microenvironment created by clothing. Most researchers agree that several key parameters interact to influence an individual's feeling of comfort or discomfort regarding clothing (Branson et al., 1988; DeMartino et al., 1984; Fahmy & Slater, 1977; Fuzek, 1981; Fuzek & Ammons, 1977; Morris et al., 1985; Pontrelli, 1977; Slater, 1977; Yoon, Sawyer & Buckley, 1984). One category of variables contains physical factors such as: the physical activity level of the wearer; environmental conditions of heat and moisture; heat, air and moisture transport properties of the fabric; fiber content; textile characteristics such as stiffness, surface roughness and stretch; and ease

in the garment's cut. Another category includes psychological factors such as appropriateness for the occasion of wear, tactile aesthetics, personal fit, and aesthetic appearance. Pontrelli (1977) adds a third category consisting of stored modifiers such as past experiences, fantasies, idiosyncrasies, expectations and lifestyle, which form a filter through which physical and psychological factors are processed. Pontrelli uses the term "comfort's gestalt" to imply that the sensation of comfort results from immediate, simultaneous interaction between physical, physiological, psychological and filter factors.

Some investigators have attempted to define comfort more objectively by measuring levels of physical factors associated with the sensation of comfort. Gagge (1981) determined that the average skin temperature for comfort varied with activity level, decreasing in a linear fashion as metabolic rate increased. Comfort ratings have been strongly linked with skin wettedness levels by a number of researchers (Andreen et al., 1953; Berglund et al., 1985; DeMartino et al, 1984; Galbraith et al., 1962; Holmér & Elnàs, 1981; Nishi & Gagge, 1970; Tokura & Midorikawa-Tsurutani, 1985; Vokac et al., 1972). As little as 3 to 5% added moisture can trigger discomfort, and the sensations increase consistently with skin wettedness in resting individuals (Scheurell et al., 1985). During vigorous exercise, however, sweat production eliciting a latent heat loss of about 40% of the increased heat production of the body is desirable for comfort (Cena & Clark, 1981; Fanger, 1973).

Researchers have not been consistently successful using physical tests to predict overall comfort. Morris, Prato and White's (1984-85) laboratory measurements of fabric weight, thickness, moisture absorption, air permeability, compressibility and resiliency were poor predictors of comfort sensation. Fuzek and Ammons (1977) point out that analysis of all known or suspected variables influencing comfort cannot fully describe this complex sensation. McIntyre further asserts that:

> Comfort cannot be predicted from first principles, nor solely from a knowledge of physiology and the physics of heat loss. The prime data on comfort conditions is obtained by exposing subjects to different environments and asking them how they feel. (1981, p. 196)

Hence, the ultimate criteria is that if a person says he or she is comfortable, then he or she is comfortable--perceptual data is the final answer (DeMartino et al., 1984).

Effect of Protective Clothing Wear on Agility. Research evaluating the effect of clothing ensembles on agility is scarce. As part of an evaluation of the effect of military load carrying on combative movement performance of men and women, Martin and Nelson (1985) administered a simple agility run. Wearing various combinations of clothing and gear ranging from less than 1 kg to more than 36 kg, subjects ran out and back through a series of four circular obstacles positioned approximately 3 m apart, passing on alternate sides of the obstacles. Performance on the agility course decreased significantly in a nearly linear fashion as the load was increased. In a more relevant study, Haisman and Crotty (1975) investigated the effects of various styles and weights of body armor on various measures of performance. Soldiers completed an 8 km march wearing either a standard combat uniform, the uniform plus a 2.5 kg armored vest, or the uniform plus added weight equivalent to the vest. Subjects performed an agility test both immediately before and immediately after the march. The post-march agility scores were significantly slower than pre-march scores, with the armored vest responsible for the slowest times.

Previous Research on the Performance of Sports Bras and Related Shock Absorbent Sports Equipment

Sports Bras. The American Society for Testing and Materials (ASTM) Committee F-8 on Sports Equipment and Facilities, has written a standard (Designation: F-753-87) which classifies and defines brassieres worn for sport or other physical activities according to function. Protective is defined as "having the ability to reduce injury from external objects," and supportive is defined as "having the ability to reduce injury from internal factors" (ASTM, 1990, p. 342). Supportive brassieres "are those intended to limit the displacement of breast tissue during physical activity," while protective brassieres "are those intended to provide safety from external objects impacting the breasts" (ASTM, 1990, p. 342). Two subclassifications have been identified for protective bras. Type 1 is designed to protect against impacts from large, low-velocity objects with negligible potential for penetration, such as a basketball or the elbow of another player. Type 2 is designed to protect against impacts from small, high-velocity objects that could involve significant penetration, such as the puck in hockey and the foil in fencing.

Supportive sports bras have been studied to a much greater extent than protective ones, partially due to the fact that many more women utilize supportive bras than protective ones. In 1990, the supportive sports bra market was $60 million and growing (Adams, 1990). While several studies relating to supportive bras were found, no studies examining any aspect of the need for or performance of protective bras appear to exist.

Studies pertaining to supportive sports bras have generally fallen into two categories: (1) informal survey debates over whether specially designed sports bras are necessary, and if so, which styles are best; and (2) biomechanical studies of breast displacement. Most studies have recommended that female athletes wear special sports bras to minimize breast discomfort during strenuous activity (Gillette, 1975; Haycock et al., 1978; Haycock, 1979; Hunter & Torgan, 1982). Several studies have used biomechanical techniques to investigate displacement of the supported and unsupported breast. Haycock (1978) filmed five athletes walking and jogging on a treadmill wearing their own bras, specially fitted bras, and no bras. The specially fitted bras markedly restricted both vertical and lateral breast displacement. Gehlsen and Albohm (1980) used high speed film techniques to determine (1) whether sports bras differ in the amount of support they provide; (2) the normal acceptable range of breast motion for comfort; and (3) the effects of additional binding of the breasts while jogging. The eight bras tested differed significantly in the mean vertical displacement of the breasts allowed in relation to the body during one running stride. The researchers found that a binding placed over the bra prevented more than 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. Lawson and Lorentzen (1987; 1990) examined both quantitative cinematographic displacement data and post-exercise evaluations of perceived comfort and perceived support for seven marketed sports bras. The bras differed significantly in control of vertical displacement and in mean perceived comfort scores. Correlations among vertical displacement values, subjective measures of support, and subjective measures of comfort were calculated. The correlation coefficients indicated that while bras which scored higher on comfort tended to be less effective at controlling breast displacement, there were exceptions to this trend. The presence of few significant correlations between subjective ratings of support and quantitative film data suggested that the perception of support is more complex than the mere feeling that vertical motion had been restricted.

Shock Absorbent Sports Equipment. According to Nigg (1990), "the cushioning ability of a material can be described as its potential to reduce impact peak forces [p. 132]." Watkins (1984) further specifies that impact-protective materials for clothing should: 1) transform the kinetic energy of the impacting projectile into a less harmful form of energy; 2) spread out the force of the impact over as wide a body area as possible; 3) prevent the projectile from penetrating the protector and causing surface damage; and 4) allow the projectile and/or the body to decelerate gradually upon contact.

No studies were found investigating shock absorbency characteristics of body padding systems for contact sports. It is not surprising that little literature emanates from the manufacturing sector. While this type of research is frequently conducted by manufacturers of protective sports equipment, the procedures and findings often remain proprietary for several reasons. First, product claims used for promotion and marketing may be based on in-house research. Potential competitors will have more difficulty challenging or refuting claims if they are not able to replicate the study because of lack of access to the protocol. Second, the increasingly litigious attitude of society has resulted in a preoccupation with potential liability. While manufacturers of protective equipment realize and claim that their products can only reduce the injury rate, some equipment users apparently believe manufacturers should be held potentially liable for all injuries, even those resulting from irresponsible actions and poor conditioning on the part of the user. When protective equipment does fail to totally protect from injury, the user may hold the manufacturer responsible and seek substantial compensation. Burns (1986) cites the case of an individual who threatened a law suit because a minor injury had been received while wearing the protective equipment, totally disregarding the fact that at the same time the equipment had prevented a very serious injury from occurring. The methods and specifications that equipment manufacturers use in product development and testing can become potential weapons to be used against them. A skilled personal injury lawyer could use the information to persuade a judge or jury that the manufacturer was negligent by not establishing adequately rigorous product specifications and test methods, and is hence liable for the injury to his or her client. Considering the liability risk, it is not surprising that in-house research data remains proprietary.

The ASTM Committee F-8 on Sports Equipment and Facilities has enabled a coalition of representatives from manufacturing, academic, and regulatory sectors to create voluntary consensus standards for the shock absorbency of sports equipment. ASTM currently publishes standard test methods for the shock-absorbing properties of playing surface systems and materials (Designation: F-355-86) and for the shock-attenuation characteristics of protective headgear for football (Designation: F-429-89).

The test method for playing surface systems and materials specifies dynamically impacting the playing surface with one of three projectiles: (1) a cylindrical missile with a flat metal impacting surface, (2) a missile with a metal hemispherical impacting surface, and (3) with a standard metal headform. The acceleration/time history of the impact is monitored by a missile-mounted transducer interfaced with a recording device. Quantities of interest include maximum acceleration in the time-acceleration history (G_{max}), time from initial impact to G_{max} (TG_{max}), and Severity Index, which is the time integral of acceleration exponentiated 2.5 times.

In the test of protective headgear for football, the headgear is attached to a standard metal headform which is connected to a free fall drop assembly carriage. The mounting is adjustable to allow any prescribed location on the head to be impacted. As the assembly is dropped onto a modular elastomer programmer (MEP) surface, an acceleration transducer monitors the acceleration-time history of the impact. Quantities of interest include G_{max} and the duration of the impulse (ASTM, 1990).

Work on a test method for body padding systems design for use in contact sports has been in progress by an ASTM task group for several years. This drop test method, however, remains in the draft stage due in part to the difficulties inherent in devising one protocol to cover the wide range of padding materials and structures, projectile masses, projectile velocities, and surface contact areas found in the relevant sports.

In one tangentially related study, Francis, Leigh and Berzins (1988) used the ASTM F-355-86 technique to investigate the shock absorbing characteristics of floors used for dance exercise. A 9.07 kg cylindrical missile with a flat 12.8 cm face was dropped from a height of 0.6 m onto 1.22 m^2 samples of 13 different floor configurations. The types of floor specimens examined included complex fabrications of carpet covered polyethylene foam, hardwood over polyurethane shock absorbers, hardwood over polyethylene foam, hardwood over steel leaf springs, foam-backed carpet over foam action blocks, and carpet-covered plywood over helical steel springs. Two quantitative parameters, G_{max} and TG_{max}, were examined, as it has been suggested that lower G_{max} and higher TG_{max} values are associated with more effective shock absorption. When analyzing the data, the researchers concluded that the variability in materials and construction among the floor samples made statistical comparison of mean G_{max} and TG_{max} values inappropriate. There were no consistent trends in the relationship between G_{max} and TG_{max}, i.e., decreases in G_{max} were not necessarily accompanied by increases in TG_{max}, leading the investigators to conclude that the use of these two descriptors as specified in the F-355 test "may be appropriate for structurally simple materials such as sheets of sponges and foams, [but are]...not appropriate for more complex systems" (Francis et al., 1988, p. 292). The geometries of the entire acceleration-time histories of the samples were qualitatively analyzed to explain the mechanical cushioning behavior of each floor type.

While the dearth of existing research regarding the shock absorbency characteristics of protective equipment makes it more difficult to underpin this study with literature, the conspicuous lack of work in this area also constitutes a strong argument for the need for further research into protection of the athlete in contact sports.

Chapter 3

METHODS

When evaluating the effect of clothing or equipment on various physical and physiological performance parameters, it is possible to approach the analysis on several levels. The United States Army Research Institute of Environmental Medicine (USARIEM) uses a five-level model which summarizes the basic types of analysis currently found in apparel and equipment research: 1) physical testing of material swatches using classical textile testing methods; 2) evaluation of complete clothing/equipment ensembles on "sweating" copper manikins; 3) active physiological trials carried out in controlled indoor environmental conditions by subjects dressed in the clothing/equipment ensembles under analysis; 4) small scale studies of simulated tasks carried out in the field by subjects wearing the specified clothing/equipment ensembles; and 5) clothing/equipment system studies conducted during actual field operations (Goldman, 1981).

Whereas data from physical testing can be helpful in screening out textile materials clearly unsuitable for a particular end use,

> Measurements made on fibers or fabrics alone may have little relationship to characteristics of actual garments made of the same fibers and fabrics, particularly when worn with other garments in an ensemble. (Huck, 1986, p. 41)

Heated manikins cannot replicate the effects of movement on clothing performance, nor provide perceptual evaluation of human comfort factors. It is thus desirable to select techniques utilizing the entire clothing/gear configuration worn by humans under dynamic exercise conditions, represented by the three highest levels of the USARIEM analysis model cited above. This laboratory-based study is most representative of level three of the model.

As discussed previously, the paucity of research evaluating the effect of protective sports equipment on performance necessarily means that an

As discussed previously, the paucity of research evaluating the effect of protective sports equipment on performance necessarily means that an established methodology for testing chest/breast protectors and other body padding systems does not directly exist. It is possible, however, to look in several related directions for help in developing appropriate methods for this research.

For example, metabolic techniques previously used and validated in running economy and load carrying studies were utilized in this study. The extensive work of textile and clothing researchers who have developed sophisticated objective and subjective methods for describing the apparel/body interface were referenced. The agility portion of a standardized motor ability test was adapted to the goals of this research.

This chapter describes the data collection protocol, equipment, and procedures used for evaluating the effect of protector wear on performance and comfort, the techniques for measurement of protector cushioning response to impact, and the statistical treatment of the resulting data.

Selection of Subjects

The ten subjects involved in this study were females between the ages of 27 and 41 years (mean = 31.8 $\pm$ 3.9 years) who had regularly run between 10 and 40 miles a week for at least one year prior to the study. Since physical build and breast size have been shown to affect garment wear and evaluation (Morris et al., 1972; Lawson & Lorentzen, 1990), and since medium or large subjects have been found to be more sensitive to comfort factors than small sized subjects (Fuzek & Ammons, 1977), an anthropometrically modal group representative of typical users was chosen. Consequently, the selected subjects' body fat levels fell in the range of 10.5% to 24.0% and their brassiere sizes ranged from 34 A or B to 36 A, B or C. Descriptive statistics are detailed in Table 1.

Informed consent was obtained from each subject prior to data collection. Treatment of subjects conformed to the human subject research policies and regulations of Oregon State University and the American College of Sports Medicine.

Interested subjects were screened through physical measurement to determine brassiere size and through hydrostatic weighing to determine percent body fat. Vital capacity was obtained using an Ohio 827 dry rolling spirometer interfaced to an Apple IIE computer. Residual volume was predicted as 28% of vital capacity (Wilmore, 1969). Prior to underwater weighing, subjects were weighed on a Homs 300 AD full capacity beam scale calibrated to the nearest .10 lb. During underwater weighing, subjects were seated in a chair suspended from a Masstron Scale Inc. ML 12210 load cell attached to a quarter ton Ton Jet mechanical crank. Water temperature in the stainless steel tank was maintained at 36°C. Repeated hydrostatic weighing trials at residual volume were administered until three consistent maximal attempts were attained. The average of the three highest trials was used in percent body fat calculations (Katch, 1968).

Table 1

Subject Vital Statistics

Subject	**Age** (years)	**Height** (cm)	**Mass** (kg)	**Body Fat** (%)	**Bra Size** (chest & cup)
1	29	174.3	63.7	14.7	34B
2	27	167.6	63.7	21.2	34B
3	32	162.6	54.5	24.0	34B
4	29	166.0	66.9	18.3	36A
5	34	152.7	49.7	10.5	34B
6	33	162.6	57.5	15.8	34A
7	29	162.6	59.3	11.3	36C
8	31	160.9	51.1	18.3	34B
9	41	162.9	59.4	23.0	34B
10	33	166.4	53.1	13.6	34A
Mean	**31.8**	**163.9**	**57.9**	**17.1**	**N.A.**
± S.D.	**± 3.9**	**± 5.5**	**± 5.8**	**± 4.7**	

The majority of subjects were experienced treadmill runners. Those without experience were given instruction and practice on the treadmill prior to the maximal exercise test to attain an acceptable level of familiarization and subjective comfort with the apparatus (Morgan, Martin, Krahenbuhl & Baldini, 1988). In addition, subjects were given practice inserting and removing the suspended mouthpiece/low resistance breathing valve apparatus used for respiratory gas exchange analysis.

General Procedures for Data Collection

Ambient temperature and relative humidity conditions could not be closely controlled in the Human Performance Laboratory. Gross adjustments were made as needed, using the laboratory's permanent cooling system, to bring the ambient dry bulb temperature to within the range of 19.5°C to 24.0°C (mean temperature = 21.53° ± 1.08) over the period of all trials. Because Fanger's (1970) comfort equation predicts that fairly large changes in relative humidity (RH) have only a small effect on preferred warmth at moderate air temperatures (an increase in relative humidity from 20% to 75% would reduce preferred temperature by only about 1°K), relative humidity was allowed to fluctuate normally within the range of 52% to 84% (mean RH = 65.1 ± 6.5%). Daily ambient conditions were recorded, and statistical examination of the data confirmed the absence of any systematic effect of ambient condition fluctuation on either physiological or perceptual data.

To make the daily exercise bouts in the still air of the laboratory more tolerable, constant moderate-velocity air ventilation was directed toward the right lateral surface of the legs of each subject during treadmill running and cooldown. Because the ventilation was directed away from the local areas being studied and because each protector posed a relatively impermeable barrier between any potential ventilation and the chest, it is assumed that this ventilation did not affect local skin temperature and comfort measures (Gagge, 1981; Gonzalez & Cena, 1985; Stuart & Denby, 1983).

A test of maximal aerobic capacity (VO_{2max}) was administered to each subject to determine the treadmill speed needed to produce a standardized workload across all subjects. On five consecutive days of the following week, each subject performed a 30 minute submaximal run at 70% of VO_{2max} wearing each of the four selected chest/breast protectors and completed one control run wearing no protector, in a randomly assigned order.

A standardized ensemble of an Olga's Christina sports bra/top, nylon running shorts, and Coolmax™ athletic socks provided by the researcher were worn in all conditions (except for that of the JBI Breast Guard which, as will be noted below, is specifically designed to be worn without an additional brassiere). The Olga's Christina sports bra/top was selected as the control brassiere because it is representative of the style and fabric content of sports bras currently utilized by a majority of active women. Each subject provided and wore the same pair of athletic shoes for all trials.

Upon arrival at the laboratory for daily testing, each subject donned the standardized clothing ensemble without the protector, determined pre-exercise body weight, donned the protector, was re-weighed, and then completed an agility test wearing the protector randomly assigned for that day. Protocol for the subsequent physiological and comfort trial included placement of temperature sensors and re-donning of the randomly assigned chest/breast protector. Each test session consisted of a thirty minute sedentary acclimatization period during which electrodes and sensors were prepared and attached, a three minute warm-up run on the treadmill, a thirty minute run at the subject's predetermined submaximal pace, a five minute cool-down walking period at 2 mph, and a five minute seated resting period. Respiratory gas exchange determinations, local temperature measurements, and perceived comfort ratings were obtained during the last two minutes of the thirty minute acclimatization period, during minutes 4-5, 9-10, 14-15, 19-20, 24-25, and 29-30 of the thirty minute run, during the last two minutes of the five minute cool-down, and during the last two minutes of the five minute rest period.

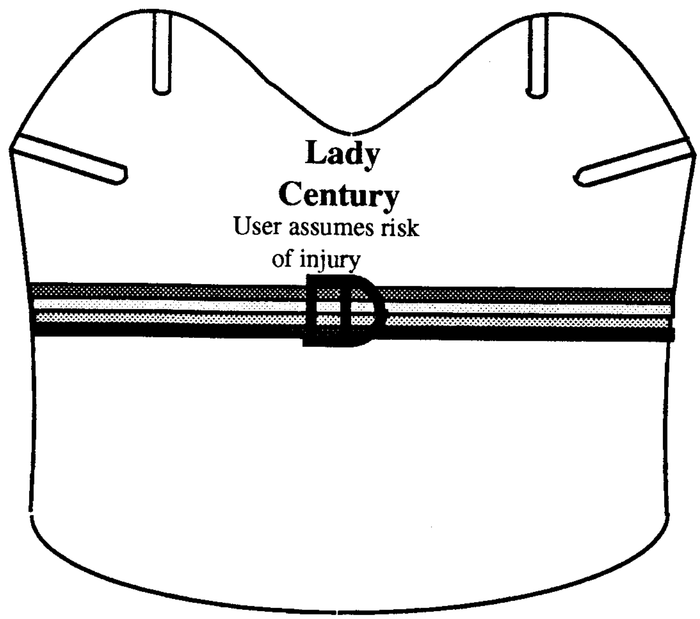
Description of Protectors Tested

Four chest/breast protectors deemed to be the most typical in style and materials technology of currently available protective sports gear were selected for evaluation. Three protectors utilize rigid polyethylene materials, and one is constructed of flexible, closed cell polyurethane foam. Each is described in detail below.

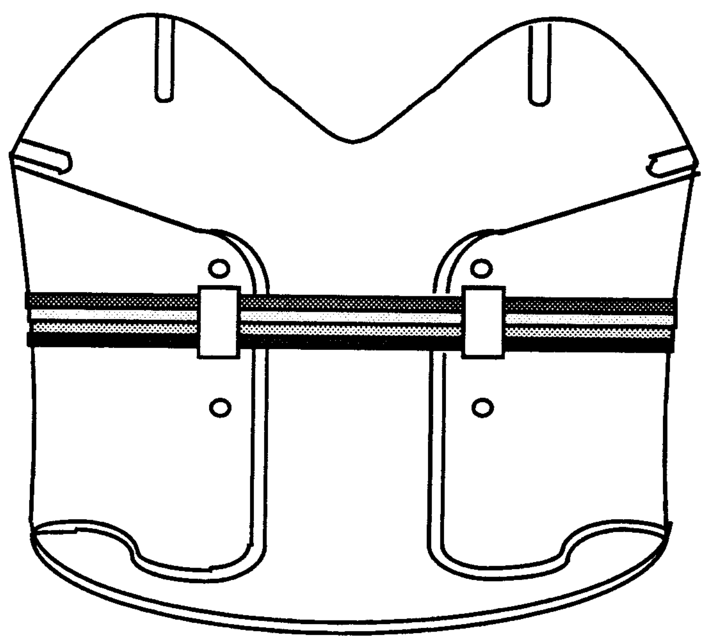
The Century Women's Rib Guard is designed to cover the chest, ribs, kidneys and solar plexus (Figure 1). It is constructed of 1/2" thickness high density Uniroyal Ensolite® closed cell foam coated with multiple layers of polyurethane vinyl. The upper front of the protector is curved to accommodate the breasts. The protector wraps around the sides of the body and partially covers the back. It employs a single adjustable belt of 1" nylon webbing for attachment to the body. The Century Rib Guard is designed to be worn over the regular bra, and is available in one size which purportedly fits all adult women. The weight of the protector used in this study is 300 g.

The FemGard Protective Bra is specifically designed to protect soft breast tissue, and is composed of two separate conically shaped polyethylene cups (Figure 2). The plastic at the perimeter of each cup has been tapered to a thinner gauge for added flexibility in the areas where the cup contacts the chest or breast. Each cup contains seven elliptical ventilation holes at center front. The two cups are connected at center front by an adjustable elastic cord that is laced through three of the ventilation holes on each cup. An adjustable strip of 1/2" elastic attached to the outer side edge of each cup stretches across the back of the body. The FemGard is designed to be worn over the regular bra, never by itself. It is available in two sizes: Small A (to fit over bra sizes 32 A, B, and C; 34 A, B; 36 A, B; and 38 A), and Medium B (to fit over bra sizes 32 D; 34 C, D; 36 C, D; 38 B, C; and 40 A, B). In the Medium B size used in this study, the weight of the protector is 73 g.

The JBI Breast Guard is designed to cover the breasts and sternum (Figure 3). It is constructed of two basic elements: rigid high density polyethylene cups, and a padded fabric carrier which resembles a

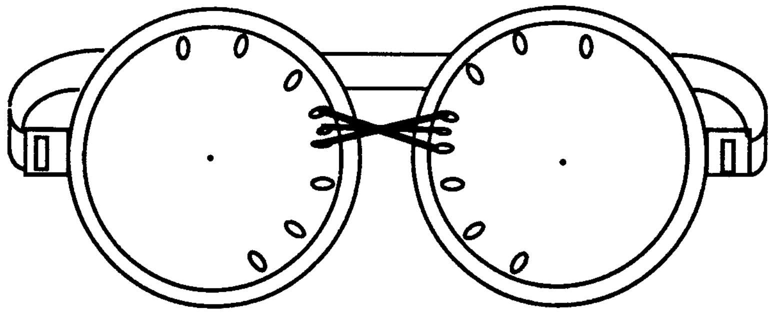


Front View

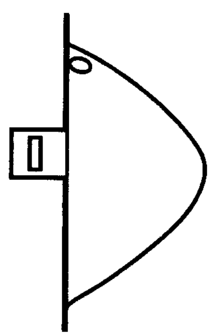


Back View

Figure 1. Century Rib Guard



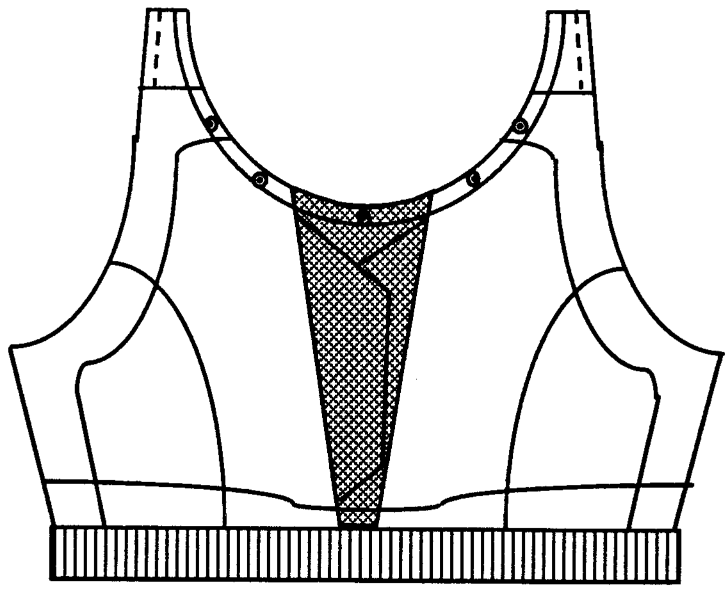
Front View



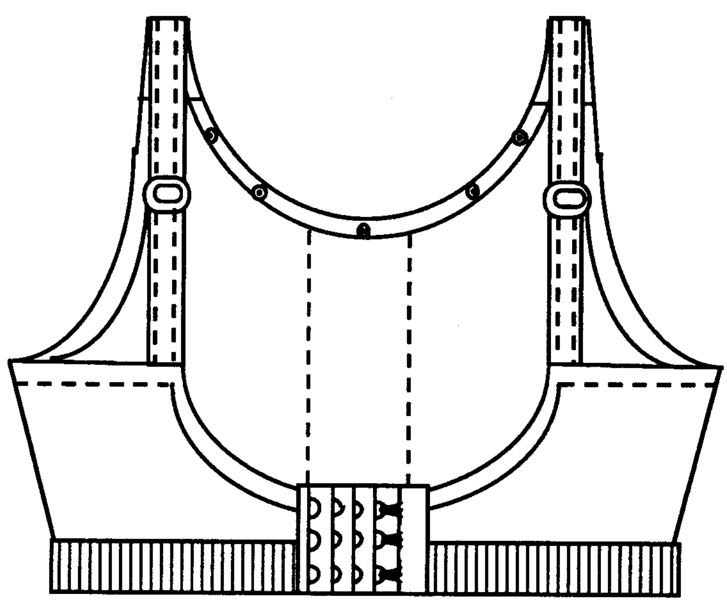
Side View of Right Cup

Figure 2. FemGard Protective Bra

conventional bra. The Breast Guard is designed to be worn alone; it is not necessary to wear a conventional bra underneath. The cups are perforated as illustrated to enhance ventilation. They are inserted into a snap-closed compartment in the fabric carrier. The cups articulate in an overlapping manner at center front to afford additional sternal protection and accommodate lateral arm flexion, and extend to the midaxillary line at the side. The fabric carrier incorporates areas of padding to minimize contact between the body and the rigid cups, and mesh areas to enhance ventilation. The front inner layer of the fabric carrier is constructed of Coolmax™ to facilitate moisture transport away from the skin surface. The shoulder straps and rib band are adjustable. The Breast Guard is available in five sizes: Size 1 (to fit 32-34 A; Size 2 (to fit 36-38 A-B); Size 3

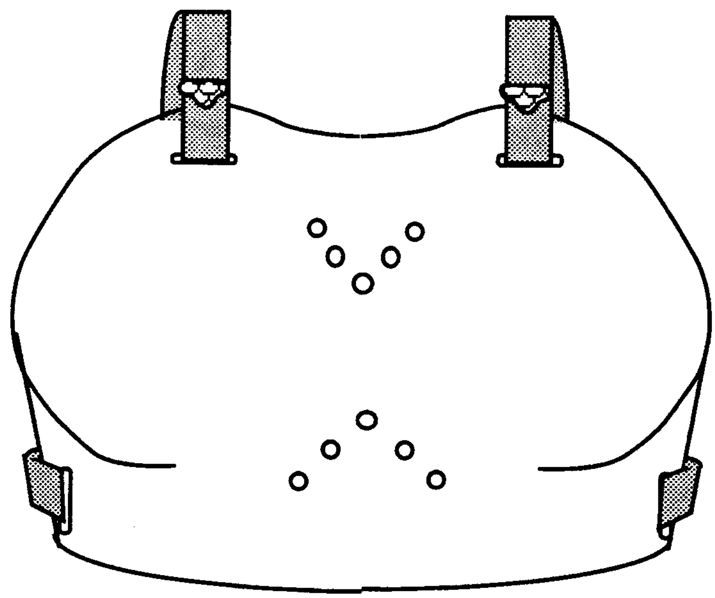


Front View

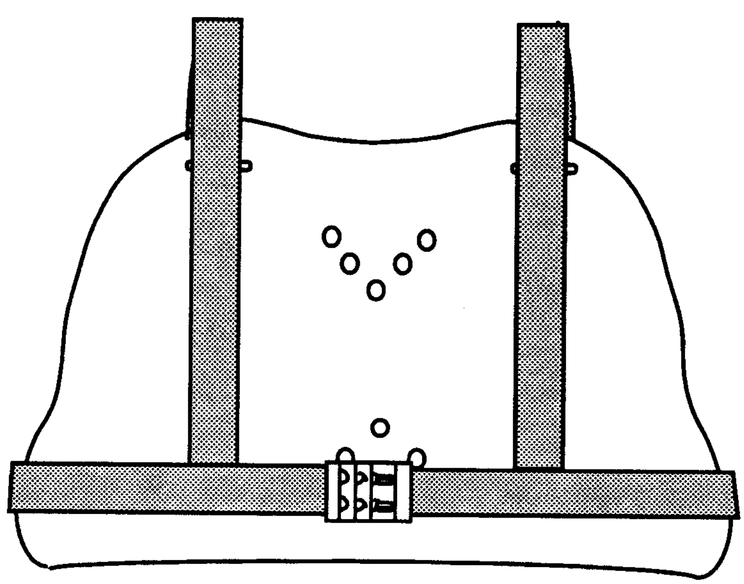


Back View

Figure 3. JBI BreastGuard



Front View



Rear View

Figure 4. Richmar Chest Protector

(to fit 34-36 B); Size 4 (to fit 34-36 C); and Size 5 (to fit 36-38 C-D). The Size 3 protector used in this study weighs 94 g.

The Richmar Chest Protector is designed to protect the breast, chest, and rib areas of the body, and is composed of a single molded piece of high density polyethylene (Figure 4). Ten ventilation holes are located at upper and lower center front. The protector extends at the side to the midaxillary line. It is secured to the body with adjustable elastic 1 1/2" rib band and 1" shoulder straps. The Richmar Chest Protector is designed to be worn over the regular bra, and is molded in four cup sizes and shapes: Junior, A, B, and C. It may be further trimmed with scissors in the armhole area to minimize chafing. The weight of the size B protector used in this study is 190 g.

Metabolic Data Collection Methods

To establish maximal aerobic capacity (VO_{2max}), subjects underwent a progressive running exercise test on a motorized Quinton treadmill following a Modified Åstrand Protocol (Pollock, Wilmore & Fox, 1984). Following a five minute warm-up at a light workload, subjects began to run at a moderate, self-selected speed in the range of 5-7 miles per hour. Subsequently, the intensity of the exercise was increased every second minute by increasing the grade of the treadmill in 2% increments until functional limitations were reached. Heart rate was continuously monitored electrocardiographically with a Quinton 630A ECG monitor. The highest oxygen uptake obtained during the maximal test was accepted as the subject's VO_{2max}.

For the subsequent test protocol to determine the added metabolic cost of wearing each chest/breast protector, the treadmill was set at the speed necessary to elicit a workload of approximately 70% of each subject's VO_{2max} value. Submaximal treadmill running was selected as the means of creating the metabolic workload in this repeated measures study since it has been shown that stable intraindividual values of treadmill running economy can be obtained when footwear, treadmill running experience, time of day, and training activity are controlled (Morgan et al, 1988). Subjects completed the submaximal protocol on five consecutive days, in either the control condition (no protector) or wearing one of the selected protectors. Sequence of wear was randomly ordered using a balanced Latin Square design for five treatments in which each protector was worn first, second, etc. an equal number of times to minimize any effects due to treadmill acclimatization or other learning. The same treadmill speed was used for each of the five submaximal runs for each subject, and treadmill speed was calibrated during the first minute of each run.

For the VO_{2max} test and all subsequent metabolic testing, the subject breathed through a 2-way low resistance breathing valve, with inspired air being measured by a Parkinson-Cowans dry gas meter. Exhaled air was conducted to a four liter mixing chamber. Gases were continuously sampled from the mixing chamber using an Applied Electrochemistry S3-A O_2 analyzer and a Sensormedics LB-2 CO_2 analyzer to determine the oxygen and carbon dioxide concentrations, respectively. Gas analyzers were calibrated prior to each test session using standard reference gases. The dry gas meter and gas analyzers were interfaced with an Apple II+ microcomputer utilizing Rayfield software, enabling real time calculations of respiratory gas exchange data. An average of the five VO_2 values obtained at minutes 10, 15, 20, 25 and 30 of each experimental condition was used for statistical analysis.

Local Skin Temperature Data Collection Methods

To examine the effect of chest/breast protector wear on local skin temperatures interior to the protector, temperature values were obtained at two sites: 1) on the sternum located vertically on a line connecting the two nipples and located horizontally on the frontal body axis; and 2) at the base of the left breast located vertically where the breast meets the chest wall and horizontally directly below the nipple (Figure 5). In order to establish a temperature differential and thus estimate the effect of each protector on heat flow away from the body, temperature values were also obtained on the outer surface of the protector directly exterior to the two sites described above.

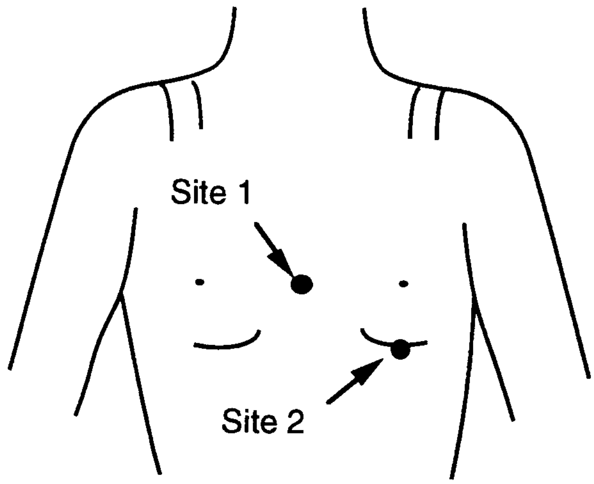


Figure 5. Skin Temperature Sensor Sites

Data were obtained both in the control (no protector) condition and in each of the four test conditions, in randomly assigned order as described above. Temperature readings were taken during the last two minutes of the thirty minute acclimatization period, during minutes 4-5, 9-10, 14-15, 19-20, 24-25, and 29-30 of the thirty minute run, during the last two minutes of the five minute cool-down, and during the last two minutes of the five minute rest period. Temperatures were recorded to the closest 0.1°C, and the value observed at each site at minutes 29-30 of the thirty minute run was used to analyze temperature during exercise. Data obtained during minutes 4-5 of the five minute rest period were used for analysis of post-exercise values.

The measurement of local skin temperature generally utilizes one of two types of instruments: contactless instruments such as infrared techniques (Clark, Mullan & Pugh, 1977), and contact instruments such as thermocouples and thermistors. Contactless instruments have the advantages of being able to simultaneously monitor the temperatures of many discrete locations and of not interfering with normal heat exchange. However, contactless methods also have the disadvantages of higher cost and limited absolute accuracy, and, more importantly, cannot be used beneath clothing (Livingstone et al., 1988; Mahanty & Roemer, 1979).

Standard point contact techniques utilize small thermistor sensors, thermocouples, or larger disk sensors generally attached to the skin with surgical tape. While contact instruments are economical and are routinely utilized (Goss, Herbert & Kelso, 1989; Holmér & Elnäs, 1981; Jeong & Tokura, 1988; Laing & Ingham, 1984-85a; Livingstone et al., 1988; Mitchell & Wyndham, 1969; Vokac et al., 1972), they present the disadvantages of the presence of connecting wires which may interfere with physical activity, and of introducing measurement error due to improper application (Mahanty & Roemer, 1979; Stoll & Hardy, 1950). It has been shown that the amount of pressure exerted on the sensor can significantly influence the resultant skin temperature value (Jirak, Jokl, Stverák, Pechlát & Coufalová, 1975; Stoll, 1964). Sensors attached too closely to the skin impede normal local heat loss, resulting in artificially high temperature values. Sensors too loosely attached, on the other hand, allow air movement between the skin and the sensor, resulting in artificially low temperature readings (Laing & Ingham, 1984-85a).

Because the nature of the tissue (bone, muscle, or fat) underlying temperature sensors can cause temperature values to vary even when constant pressure has been exerted, contact methods do not provide absolute skin temperature values (Jirak et al., 1975). However, since this study was designed to measure deviations from a control condition, it was sufficient that the techniques used to obtain temperatures be mutually consistent; absolute accuracy was neither achievable nor required (Mitchell & Wyndham, 1979; Renbourne & Rees, 1972).

In this study, temperature data were obtained using Yellow Springs Instruments 409B attachable flat surface thermistors interfaced with a Yellow Springs Model 46 TUC Telethermometer. To minimize error, thermistors were calibrated against a standard mercury thermometer in a water bath prior to the start of each experiment. Thermistors were required to be within 0.1°C of the criterion measurement. The same thermistor was placed at the same site for every trial to further reduce error.

Thermistors were applied to the skin so as to maintain a consistent skin/sensor interface while minimizing coverage and occlusion of the site. According to the technique of Goss et al. (1989), thermistors were attached to the skin with narrow strips of water-permeable surgical tape (3M Transpore™). A larger piece of cotton athletic tape with a circular hole in the center to accomodate the thermistor was placed over the surgical tape to create a more substantial anchor without occluding the sensor. The thermistors used to monitor the temperature of the outer surface of each protector were applied to the outside surface directly exterior to the location of each skin temperature sensor using the same taping technique.

Perceived Comfort Data Collection Methods

The technical process of making judgments from perceptions is called psychological scaling and is widely applied to many types of commercial and scientific measurement, especially in the field of textiles and clothing (Hollies, 1977). These judgments can involve a single sensation, but more typically the perception involves a combination of several sensations. Some psychological scales have physical counterparts with which they may be highly correlated, a familiar example being Borg's perceived exertion scale. However, "the existence of a physical scale is not a requirement for making valuable, useful and precise psychological scaling measurements" (Hollies, 1977, p. 109).

Use of well-designed psychological scaling techniques allows maximum utilization of a human being's innate ability to perceive and evaluate complex phenomena without the interference of the instrumentation required for acquiring physical data (Hollies, 1977). And, as Cena and Clark (1981) point out, "no matter how precise the measurement of the physical variables that specify the environment, the link between that environment and its rating as comfortable or uncomfortable is through questions put to people [p. 280]." Andreen et al. (1953) assert that the comprehensive study of clothing comfort must include subjective opinion. DeMartino, Yoon and Buckley (1984) suggest that while objective measures can help to explain the results of subjective measures, they cannot replace perceptual data and that, in fact, the subjective evaluation should be the final answer. Optimally designed comfort research will include both types of analysis whenever possible.

Human perception analysis techniques have been applied to a wide variety of apparel garments worn in a range of microclimates at varying activity levels, and have been shown to provide a powerful tool and sound basis for comparing garment systems (Hollies, 1977; Hollies et al., 1979). In some cases, perceptual data have been shown to be more sensitive in detecting significant differences in clothing comfort than objective measures, particularly in moderate environmental conditions where true physiological stress is minimal (Branson et al., 1988). Indeed, because experimental conditions of environment and body activity must often be set at extreme levels in order to counteract the natural homeostatic tendencies of the body and produce differences in physiological data, subjective comfort assessment may be the most effective way of discriminating among clothing ensembles worn under more normal conditions (Laing & Ingham, 1984-85b).

According to Cabanac (1969), two elements are presumed in the formation of conscious sensations relating to comfort. The first is a discriminative element in which the subject verbally describes the physical characteristics of the stimulus, i.e., "hot," "cold," "very wet." The second is an affective element in which the subject expresses the pleasantness or unpleasantness of the perception, i.e., "somewhat comfortable," "intolerable." Local thermal sensation and humidity sensation estimates are discriminative in nature, whereas general comfort sensation estimates represent the affective component of the overall clothing sensation. Affective elements can be influenced by discriminative elements, as evidenced by Vokac et al.'s (1976) finding that comfort sensations reflected upward and downward deviations from neutral thermal sensation.

It has been shown that human sensitivity to specific gradations of intensity of a stimulus is limited to the detection of about seven steps, and that scales of three or less steps are generally too coarse for comfort research (Cena & Clark, 1981). Accordingly, each of the scales used in this research was comprised of seven steps.

While earlier comfort research concentrated heavily on overall comfort sensation, more recent emphasis has been placed on patterning regional subjective and objective responses. Vokac et al. (1971, 1972) have shown that is it possible to localize and judge specific comfort sensations independently of sensations that may be occurring in other regions of the body. Three separate perceptual scales assessing both local and general perceptions were used in this research to develop a comprehensive description of the perceived comfort of the chest/breast protectors which includes both discriminative and affective elements. They are a "Local Thermal Sensation" scale, a "Perceived Local Skin Wettedness" scale, and a "General Comfort Sensation" scale. They are described below.

Local Thermal Sensation (LTS) was assessed at the site indicated in Figure 6 using a seven step thermal sensation scale (Table 2). This widely employed scale has been found to be highly reliable for thermal evaluation in both hot and cold environments, both inside and outside the range of temperature control by sweat evaporation (Berglund et al., 1985; Berglund et al., 1986; Branson et al., 1986; Gagge et al., 1969; Galbraith et al., 1962; Hollies, 1977; Hollies et al., 1979; Holmér, 1985; Laing & Ingham, 1984-85b; McIntyre & Gonzalez, 1976; Morris et al., 1985; Nevins et al., 1975; Vokac et al., 1972; Vokac et al., 1976).

Table 2

Local Thermal Sensation Scale

1. Cold
2. Cool
3. Slightly cool
4. Neutral
5. Slightly warm
6. Warm
7. Hot

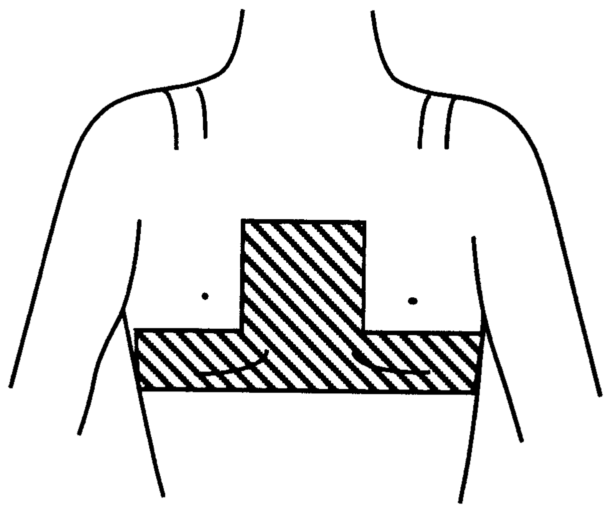


Figure 6. Chest Area Designated for Perceptual Data Collection

Gagge et al. (1969) found that, while individual sensitivity to air and skin temperature tended to decrease as subjects' maximal VO_2 increased, for the whole group a change of 7°C in ambient air temperature and of 2°C in skin temperature caused a single scale category change in warm temperature sensations during exercise at 25, 50 and 75% of maximum oxygen uptake. Their statistical analysis suggested that the standard error in predicting temperature sensation from skin temperature is approximately one scale category.

Perceived Local Skin Wettedness (PLSW) was also assessed at the same site illustrated above in Figure 6 using the seven step wetness sensation scale employed by Berglund et al. (1985) (Table 3). Local skin wettedness is a function of local sweat secretion and evaporation rates, which depend both on the water vapor pressure gradient between the skin and the ambient air, and on the resistance of any intervening clothing and its boundary layer to the passage of water vapor.

Table 3

Perceived Local Skin Wettedness Scale

1. Dry
2.
3. Damp
4.
5. Wet
6.
7. Soaking wet

Highly positive, highly significant correlations ($r = 0.82$, $p < .001$) have been found between subjective wettedness sensations and objective measures of humidity in the clothing microclimate by Laing and Ingham (1984-85b). Morris et al. (1985) found a correlation of 0.985 between perceived wettedness ratings and the amount of moisture in undergarments during exercise. Berglund et al. (1985) measured mean skin wettedness with dew point sensors during exercise at 5 METs and concluded that the subjective feeling of the level of skin wettedness correlated well with measured values ($r = 0.94$ at higher air speed, 1.4 m/s; $r = 0.91$ at lower air speed, 0.05 m/s). The regression equation relating perceived skin wettedness to measured skin wettedness at lower air speed was: Sense of wettedness = 0.25 + 0.071measured wettedness.

The high correlations between objective and subjective values suggest that when instrumentation for collecting objective data is not available, carefully collected perceptual data constitutes a valid and reliable means of assessing skin wettedness in the clothing microclimate.

The General Comfort Sensation (GCS) scale (Table 4) has been previously used by Gagge et al. (1967) and Morris et al. (1985), and employed in slightly adapted forms by Berglund et al. (1985, 1986), Holmér (1985), McIntyre & Gonzalez (1976), and Vokac et al. (1976). Pontrelli (1977) has described comfort's "gestalt" as the affective response to the interaction between physical, physiological and psychological stimuli and personal conscious and unconscious stored modifiers indicating a person's satisfaction with the clothing microenvironment. Because clothing and equipment "comfort" implies many factors beside thermal and wettedness sensations, including design, fit, fashionability, and tactile impression, the GCS scale was designed and included in the study to provide a more global picture of comfort than the two previous scales.

Table 4

General Comfort Sensation Scale

1. Comfortable
2.
3. Slightly uncomfortable
4.
5. Uncomfortable
6.
7. Very uncomfortable

Perceived comfort data were obtained both in the control (no protector) condition, and in each of the four test conditions during the last two minutes of the thirty minute acclimatization period, during minutes 4-5, 9-10, 14-15, 19-20, 24-25, and 29-30 of the thirty minute run, during the last two minutes of the five minute cool-down period, and during the last two minutes of the five minute rest period. At the appropriate times, each subject was directed to determine her subjective judgments of local thermal sensation, local skin wettedness, and general comfort by focusing on a diagram indicating the local area of interest and then inspecting a chart of the scale. Each time, the investigator used exactly the same wording to elicit the information: "Thinking of the area in the diagram, how would you describe your skin's thermal sensation (or wettedness, or general comfort sensation)?". The subject held up fingers to indicate the number that most closely corresponded with her perceptions. The researcher audibly repeated the number back to the subject for confirmation prior to recording the data. Because previous clothing comfort research suggests that thirty minutes' time may be necessary to reach a thermal and humidity equilibrium in the clothing microclimate (Ayling, 1986), data obtained during minutes 29-30 of the thirty minute run were used for analysis of perceptions during exercise. Because dampness and clamminess of garments post-exercise have been frequently observed as complaints in clothing research, and because perceived comfort differences among garments may not emerge during exercise but rather after cooldown (Morris et al., 1985), data taken during minutes 4-5 of the rest period were also analyzed.

Agility Test Methods

To evaluate the effect of chest/breast protector wear on agility, subjects performed the agility portion of a standardized motor ability test, in the control condition (no protector) and while wearing each protector, in the previously described latin square order. Subjects were familiarized with the test course by running through it twice during the week prior to data collection to help reduce any learning effect. The agility test was administered prior to the metabolic testing of each protector to minimize any effects of fatigue related to the metabolic portion of the protocol. Subjects walked once through the course prior to each day's timed trial to re-familiarize themselves with the task.

The obstacle race of the Scott Motor Ability Test was chosen as the preferred agility test because it met several criteria important to this study. First, while a majority of agility tests involved primarily running ability or leg-initiated body position changes (Johnson & Nelson, 1986), the obstacle race of the Scott Test additionally required crawling, rolling or sliding on one's chest under an 18" horizontal bar. It may thus have included an element more representative of martial arts and other contact sports which may not incorporate extensive running. It also introduced the potential for significant chest contact with the floor. Second, the test has been validated for the sex and age range of the subjects (college females). The validity criterion used was a composite score composed of expert ratings, T-scores from various sport skills, and fundamental activity achievement scores. The validity coefficient for Battery 2, of which the obstacle race is an element, is .87. Correlation of the obstacle race with the agility portion of the McCloy general motor ability test indicates an *r* of .94. Third, reliability of the test is .91 when taken on two successive days, which is crucial to the repeated measures design of the study.

The directions for the obstacle race are as follows (Johnson & Nelson,1979):

> The student starts in a back-lying position on the floor with her heels at the starting line. When given the command to go, the student scrambles to her feet and runs to the first square that is marked on the floor. She must step on this square, and on each of the next two squares, with both feet. She then runs twice around the jump standard and proceeds to the crossbar [and crawls or rolls under it], gets up and runs to the end line, touches it with her hand, runs back to line F, touches it, runs and touches the end line, runs back to F, then springs across the end line. One trial is given. The stopwatch is started when the signal to go is given and stopped when the student sprints across the end line. The score is the number of seconds, to the nearest tenth of a second, that is required to complete the course. (p. 362)

During the obstacle race, the test is not invalid if the heel or toe is not completely inside the squares during stepping, or if a subject bumps or dislodges the crossbar while passing below it. Subjects are not allowed to grasp the jump standard pole with the hand while circling it.

Because the course layout in its original form would have required subjects to run at full speed over a step and through a doorway of the Biomechanics Laboratory, slight modifications were made to the course to increase safety while retaining the integrity of the task (Figure 7). A 90° turn at the first stop box and an extra leg of the final shuttle run were added. Because turning and shuttling were already elements of the test, and because scores would not be compared to existing norms, the changes are assumed to have not detracted from the validity of the test for this purpose.

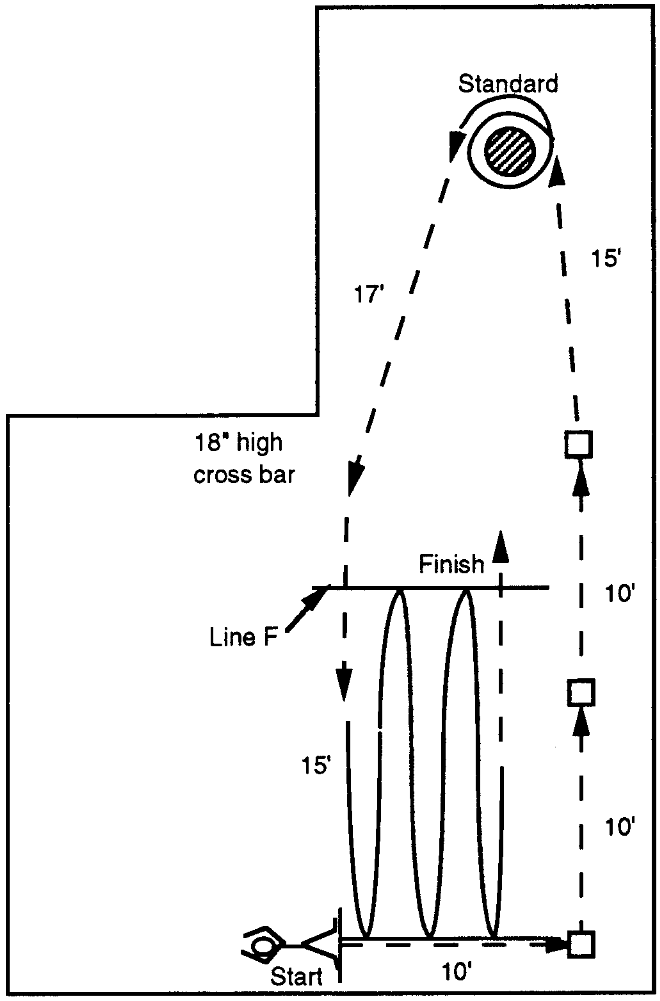


Figure 7. Agility Course as Adapted from McCloy (Johnson & Nelson, 1979)

Because the surface area and frictional characteristics of the shoe sole can affect performance on agility tests, (Johnson & Nelson, 1986), it was imperative that subjects wear the same pair of shoes for all obstacle race trials. While examination of the data indicated that learning did occur over the course of the five days of trials, the balanced latin square design of the study assured that this effect was distributed equally among all conditions.

Impact Test Methods

No established test methodologies currently exist in the literature for evaluating the cushioning properties of body padding devices such as chest/breast protectors. Test methods developed for in-house use by equipment manufacturers are generally held as proprietary information because of the liability concerns discussed in the previous chapter. American Society for Testing and Materials (ASTM) (1990) currently offers standard test methods only for the shock-absorbing properties of playing surface systems and materials (Designation: F-355-86) and for the shock-attenuation characteristics of protective headgear for football (Designation: F-429-89). The method developed for this study draws upon these tests and upon a proposed ASTM test method for body padding systems that has been in development for several years, but which remains in the draft stage.

Evaluating the cushioning ability of padding systems for a variety of sports applications poses difficult methodological problems for the sports equipment researcher, and probably explains to a large degree the lack of standardized test methods. In the methods that have been developed, the effect of cushioning on the deceleration history of a body part or projectile has been assessed using drop tests in which a known mass with a rigidly attached accelerometer impacts at a specified velocity onto the surface of interest (Nigg, 1990). Both the ASTM F-355-86 standard test method for playing surface materials and ASTM's proposed test method for body padding systems employ this type of testing procedure in which time histories of the vertical acceleration of the dropping mass during contact with a surface are recorded. The maximum deceleration in the time-deceleration history (G_{max}) and the time to G_{max} to the nearest millisecond are the calculations of primary interest in these methods (ASTM, 1989; ASTM F-8 Committee, 1989). Using Newton's second law, Force(t) = mass * acceleration(t), the contact force between the dropping mass and the cushioning surface can also be estimated (Nigg, 1990).

While off-the-body tests can be highly reliable and provide useful information about cushioning properties, Nigg (1990) cautions that they cannot be used to predict forces acting on internal body structures, only to quantify external "input" forces and provide information concerning the properties of the material being tested. Hence no physiological significance can be placed on values obtained from drop tests with respect to human tolerance.

Test Apparatus. Based on the ASTM standard and proposed test methods, a guided free-fall drop test apparatus was developed for assessing the cushioning properties of the four chest/breast protectors. The apparatus is depicted in Figure 8 and described below.

The test specimen was securely fitted to a torso-shaped anvil constructed of fiberglass and high-density polyethylene foam, covered with cotton canvas. The anvil was designed to provide rigidity and compliance characteristics similar to the human torso. The superior aspect of the anvil was contoured to allow the placement of prosthetic breasts in the correct anatomical position. The prosthetic breasts, Size 3 Amoena® Model No. 254's, were selected by a women's health care specialist with extensive breast examination experience as being particularly representative of normal breast tissue in consistency and turgor. The breasts were secured to the anvil with a 36B JBI Sportshape bra. The inferior aspect of the anvil was flat for stability. The anvil was bolted to the wood and steel framework of the apparatus at six locations around its perimeter, and the framework was secured to the laboratory floor.

A cylindrical polyvinylchloride (PVC) track (ASTM Schedule 80 PVC pipe, 5.08 cm outside diameter, 3.81 cm inside diameter) 59.6 cm long was mounted vertically on the framework above the anvil with a circular aluminum collar. The track was placed in a position to provide contact with the nipple area of the left breast. Cylindrical steel missiles 3.8 cm in diameter with a hemispherical impact surface (Figure 9) were dropped in guided free-fall down the track onto the desired location on the test specimen. The light missile was 6.8 cm in length with a mass (with attached accelerometer) of .56 kg. The mid-weight missile measured 13.5 cm in length with a mass of 1.14 kg, while the heavy missile was 27.1 cm long with a mass of 2.30 kg.

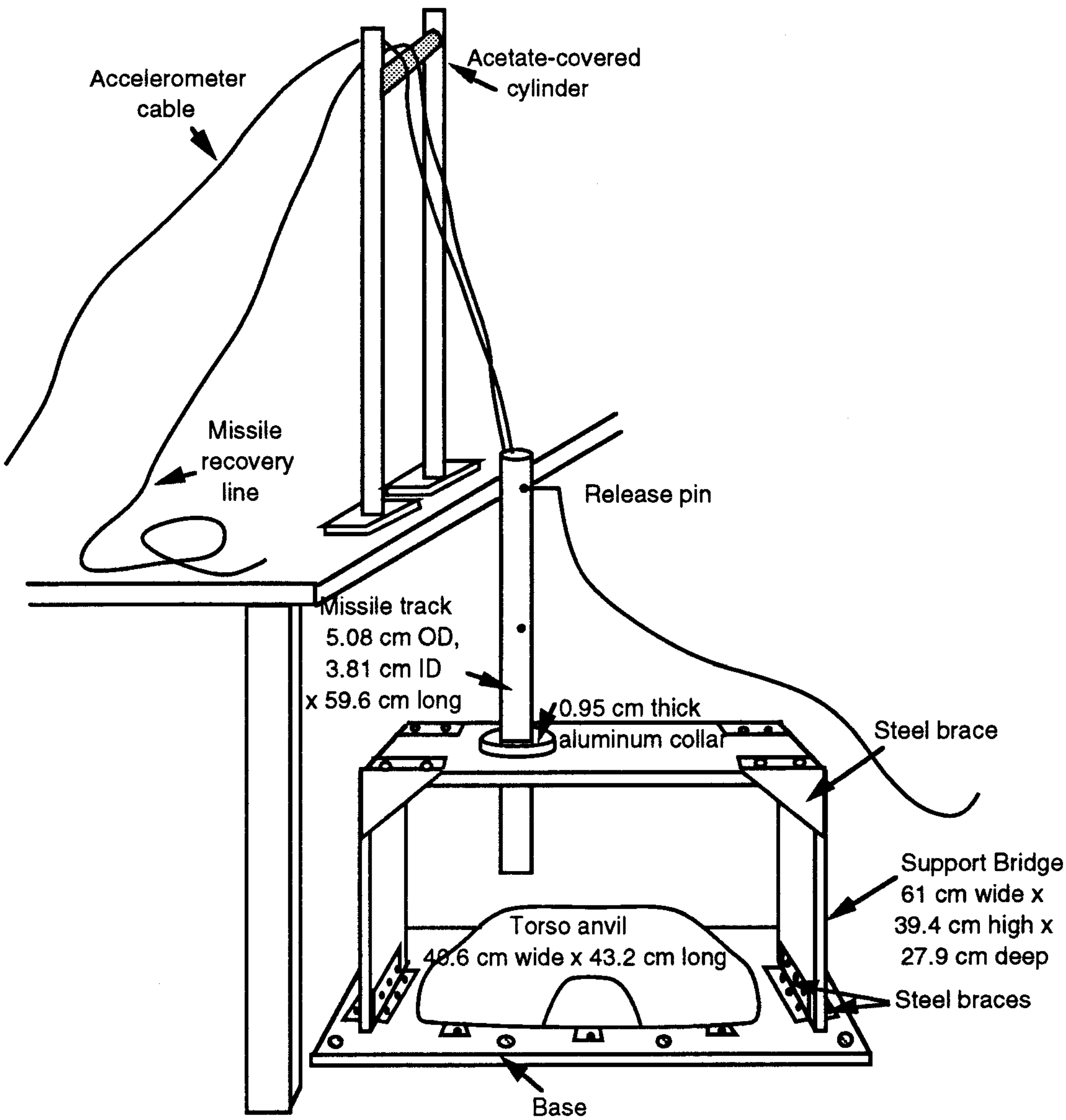


Figure 8. Impact Test Apparatus

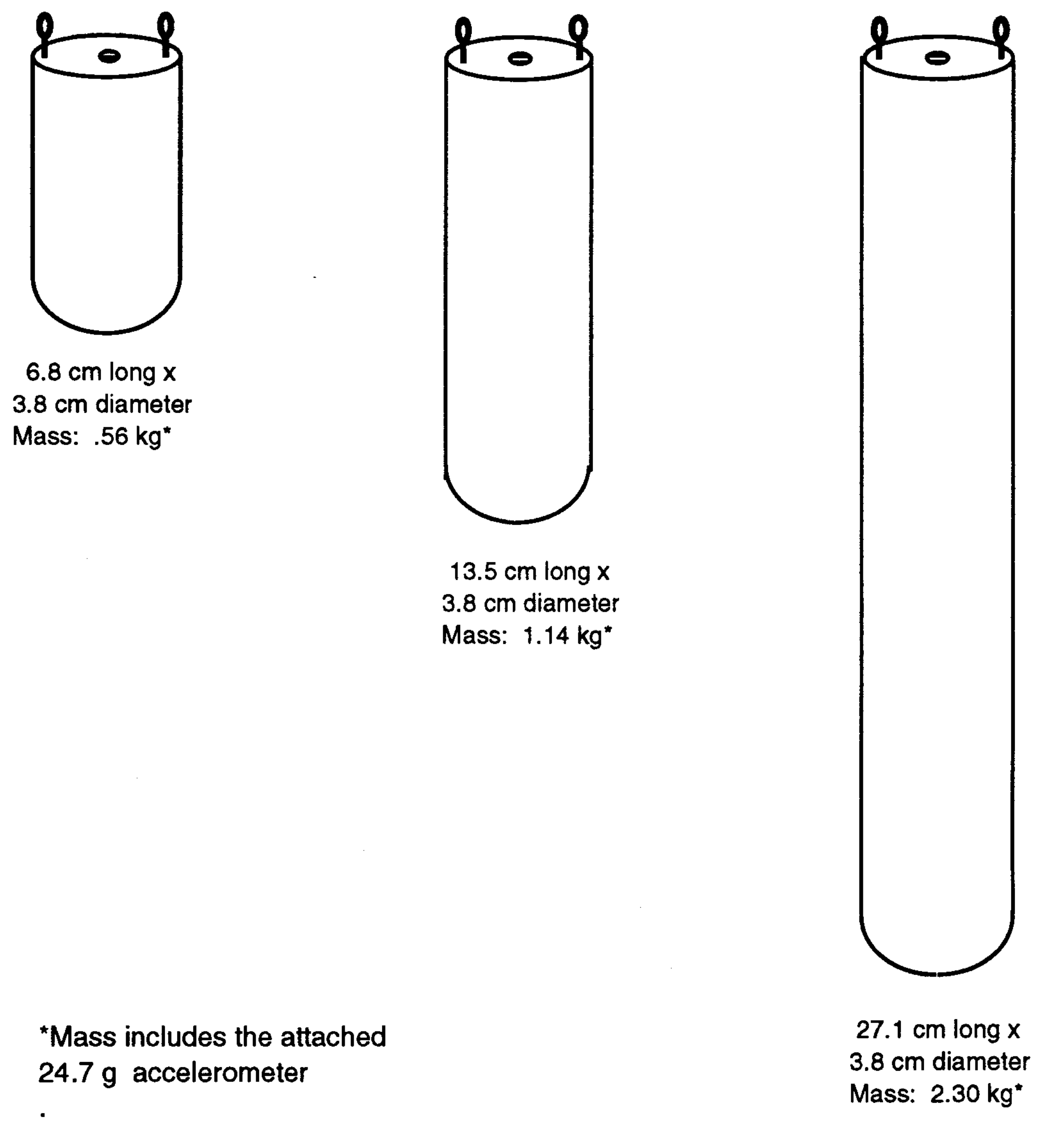


Figure 9. Missile Dimensions

Each of the three different sizes of missiles were dropped from two different drop heights. Because the top of each missile was placed in a standardized position and because each missile was a different length, the drop heights for the light, mid-weight and heavy missiles varied systematically. In addition, the differences in thickness of the four protectors introduced additional slight variations in drop heights among the protectors. The resulting drop heights and impact velocities for all conditions are found in Table 5 and Table 6, respectively. Estimates of kinetic energy (K.E.), which is the energy a body possesses because it is moving, were calculated using the relationship K.E. = 1/2 (mass)(velocity^2), and are presented in Table 7.

Table 5

Drop Heights (cm)

Test Condition:	Low Drop	High Drop
.56 kg missile		
Century	35.4	55.5
FemGard	34.7	54.8
JBI	36.8	56.9
Richmar	36.0	56.1
1.14 kg missile		
Century	28.7	58.8
FemGard	28.0	58.1
JBI	30.1	60.2
Richmar	29.3	59.4
2.30 kg missile		
Century	15.1	45.2
FemGard	14.4	44.5
JBI	16.5	46.6
Richmar	15.7	45.8

Table 6

Impact Velocities (m/sec)

Test Condition:	Low Drop	High Drop
.56 kg missile		
Century	2.58	3.08
FemGard	2.56	3.07
JBI	2.62	3.11
Richmar	2.60	3.09
1.14 kg missile		
Century	2.33	3.39
FemGard	2.32	3.37
JBI	2.38	3.42
Richmar	2.36	3.40
2.30 kg missile		
Century	1.78	2.48
FemGard	1.76	2.46
JBI	1.84	2.53
Richmar	1.82	2.51

Data Processing and Storage. A PCB Model 302A linear accelerometer, mounted on the missile, monitored the acceleration-time history of the impact. This piezoelectric quartz accelerometer is capable of measuring the acceleration aspect of shock and vibration up to 500 g with a resolution of .01 g, and has a resonant frequency of 45 kHz. Amplified analog accelerometer outputs were converted to digital format by a Metrabyte DAS-16F A-D board set at a sampling frequency of 5000 Hz. Data were transferred to a Zenith 386 Workstation Computer driven by a compiled Microsoft QuickBasic program which collected, smoothed and analyzed the data. The filtering routine which smoothed the raw acceleration data and removed the random "noise" component utilized a Butterworth 4th order (double pass) digital filter with a cutoff frequency of 500 Hz.

Table 7

Kinetic Energy Estimates (J)

Test Condition:	Low Drop	High Drop
.56 kg missile		
Century	1.86	2.66
FemGard	1.83	2.64
JBI	1.92	2.71
Richmar	1.89	2.67
1.14 kg missile		
Century	3.09	6.55
FemGard	3.07	6.47
JBI	3.23	6.67
Richmar	3.17	6.59
2.30 kg missile		
Century	3.64	7.07
FemGard	3.56	6.96
JBI	3.89	7.36
Richmar	3.81	7.25

Because the analysis software required impact velocity as an input, video techniques were used prior to impact data collection to determine the impact velocity for each experimental condition. A Panasonic Super VHS format professional/industrial video camera (AG-170) operating at a nominal frame rate of 30 hz (60 video fields per second) with an electronic shutter time of 0.001 seconds was used to record the impacts. The video images were digitized at 60 frames per second using Peak Performance Technologies, Inc.'s system and software. The video images were converted to digital format, stored in computer data files, and the data processed to yield the impact velocities.

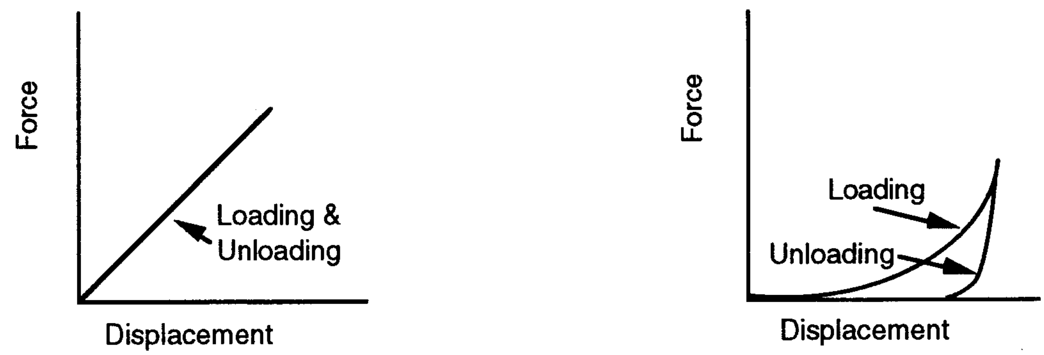
Test Procedure. The protectors were tested at ambient conditions of the Biomechanics Laboratory and were stored in the laboratory for at least four hours immediately prior to testing. Each protector was attached to the anvil in a manner that simulated as closely as possible its position during actual use. Modifications to the back side of the Century protector were made to facilitate secure attachment of the protector to the anvil. Data recording equipment was prewarmed and calibrated according to the manufacturer's recommendations.

After the protector was attached to the anvil, the appropriately sized missile was placed in the track and raised to the selected drop height. Accelerometer wiring was suspended from above over an acetate-covered (low friction) spindle so as to minimize any drag effect on the missile. The missile was then released onto the protector and anvil by pulling out a release pin located at the top of the missile. The computer was manually triggered, and the acceleration-time history of the impact collected and stored. Three consecutive drops were made at intervals of 3 ± 0.25 minutes to allow for any hysteresis of materials (ASTM F-8 Committee, 1989).

Several quantities and relationships were derived from the acceleration-time history data. First, the peak acceleration of the dropping mass during impact with the chest/breast protector was calculated to yield a measure of the shock attenuation characteristics of each protector. Second, graphic representations of complete acceleration-time histories were plotted to assist in qualitative analysis of the impact event. Third, the values needed for the creation of force-displacement curves for both the loading and unloading phases of the impact were derived as follows. The contact forces between the dropping mass and the chest/breast protector were calculated from the maximum acceleration in the time-acceleration history using the relationship Force(t) = mass * acceleration(t). In addition, two integrations were performed on acceleration data to yield displacement values.

Force-displacement curves provide a means of assessing both the stiffness and shock absorption characteristics of cushioning materials. For example, a typical force-displacement curve for a perfectly elastic material such as a steel spring is shown in Figure 10a. Because the spring returns essentially 100% of the applied energy, the loading and unloading segments are virtually identical and constant in slope. A typical force-displacement curve for a highly energy-absorbent material is shown in Figure 10b. The upper curve represents the loading phase, and the lower curve represents the unloading phase of the force application.

By observing the slope of either line at a given force level, it is possible to describe the stiffness characteristics of the material at that force level during both loading and unloading. By numerically integrating under the force-displacement curves of both the loading and unloading phases, and by calculating the difference in area between the two curves by subtracting the area under the unloading curve from that under the loading curve, an estimate of the shock absorption characteristics of each material may be derived. In the above example of the highly absorbent material, the area under the unloading (lower) curve represents only about 10% of the total area under the loading (upper) curve, suggesting that this material absorbs approximately 90% of the impact energy.



A. Typical force-displacement curve for a steel spring

B. Typical force-displacement curve for a highly absorbent material

Figure 10. Typical Force-displacement Curves for Two Materials

While drop testing is an easily implemented, widely accepted method of assessing cushioning characteristics, it is not without shortcomings, as Nigg (1990) pointed out in his review of sports surface cushioning test methods. For example, the force and acceleration values measured during impact are related to the mass of the missile, the drop height, and contact area. Nigg illustrated how changing one of these three factors will change not only impact forces for a group of tested surfaces, but can even rearrange the rank order of results for those surfaces. Because different test setups can alter peak impact force values, for a given test it may not be readily apparent whether the test results are due to differences in material properties, or are a product of the given test setup. This problem has posed one of the major barriers to the development of the ASTM standard test method for body padding. It is difficult to justify specifying a particular missile mass, radius, and impact velocity in the test method while knowing that test results will depend not only on real differences between cushioning materials but also on test setup specifications. Nigg suggested systematically varying test setup factors such as missile mass and drop height as a means of assessing any potential interaction between test conditions and material performance. To help differentiate between test result differences due to material properties and those due to setup conditions, a missile of each of the three different masses (.56 kg, 1.14 kg, and 2.30 kg) was dropped from two different drop heights, as previously specified.

Analysis of the Data

The experimental design for this study was a repeated measures design, utilizing a balanced latin square in which each subject served as a block and tested each protector in random order to control for systematic learning effects. The independent variable was five test conditions (four styles of chest/breast protectors and no protector). The dependent variables of: (1) subjects' physiological responses of oxygen uptake and local skin temperature, (2) subjects' subjective responses of Local Thermal Sensation, Perceived Local Skin Wettedness, and General Comfort Sensation during exercise and after cooldown, (3) subjects' performance times for a standard agility test, and (4) the chest/breast protectors' shock absorption characteristics as calculated using force-displacement curves, were compared using repeated measures analysis of variance methods. A Type I error rate of 0.05 was used throughout the analysis. When a statistically significant F was found, subsequent pairwise comparisons were performed using the Scheffé test. All statistical analyses were implemented in the Macintosh computer program Statview II, version 1.03 (Abacus Concepts, Berkeley, CA).

The properties of peak force and stiffness were evaluated in a somewhat more qualitative manner. Due to the heterogeneity of materials used in the various chest/breast protectors, the mechanisms by which they provide protection are quite different and certain mechanical characteristics cannot be compared directly. For example, protectors incorporating rigid area-elastic materials such as the FemGuard, the JBI BreastGuard, and the Richmar protectors operate primarily on the principles of spreading the impact over a larger surface area and of preventing the impacting object from reaching and traumatizing the biological tissue beneath. The Century Rib Guard, on the other hand, utilizes deformable closed cell foam in its construction. This point-elastic material provides protection by spreading the impact event over a longer period of time and by transforming the kinetic energy of the impacting object into potential and heat energy within the cells of the foam as it more slowly compresses and rebounds. Peak contact force values and acceleration-time histories from the drop testing of these two categories of shock absorbing materials differ considerably (Francis et al., 1988), yet one cannot categorically assert that one type of material is necessarily superior to the other. Foam materials tend to decrease peak contact forces, which is considered to be an indicator of good shock attenuation, but may not protect against indentation and penetration of tissues. A rigid material will generally produce a higher, sharper peak impact spike, but this effect is not necessarily harmful because the material rather than the body takes the brunt of the impact.

Even if statistically significant differences in peak acclerations and contact forces can be found, conclusions with regard to which protectors are superior cannot be drawn based on peak values alone. As Nigg (1990) points out, a great deal of information about material performance is lost when only isolated peak values are used in evaluation. Examination and interpretation of data across the total time history of an impact provides additional understanding of the cushioning characteristics of a material. This qualitative approach, used by Francis et al. (1988) in their evaluation of the shock absorbing characteristics of dance exercise floors, is used to present and analyze peak contact forces, acceleration-time histories, and the stiffness and shock absorbency characteristics associated with the loading and unloading phases of the impacts. The graphic presentations are accompanied by qualitative interpretations of the observed data.

Chapter 4

RESULTS AND DISCUSSION

In this study, the effects of wearing chest/breast protectors on selected measures of performance and comfort were determined. Data were obtained for five experimental conditions: 1) the control condition in which no protector was worn; 2) the Century Women's Rib Guard constructed of 1/2" thick closed-cell foam covering the front, sides and partial back of the torso; 3) the FemGard Protective Bra consisting of two conical polyethylene cups covering the breasts; 4) the JBI Breast Guard which combines a conventionally styled fabric bra with rigid, overlapping polyethylene cup inserts; and 5) the Richmar Chest Protector which is composed of a single molded piece of polyethylene covering the breast, chest and upper rib areas.

Ten females participated in the study, completing the same submaximal treadmill running protocol at approximately 70% of VO_{2max} on five consecutive days. The physiological variables of oxygen consumption and local skin temperature beneath the protectors were evaluated during the wearing of each of the four styles of protector and in the control (no protector) condition. In addition, the effects of protector wear on local thermal sensation, local wettedness sensation, and general comfort sensation in the area of the breast were evaluated using conventional 7-point scales utilized in clothing comfort research. To determine potential effects of protector wear on agility, subjects completed a standard agility course in each experimental condition prior to each day's submaximal run. The variables were analyzed for relationship to presence and style of chest/breast protector using repeated measures analysis of variance methods. The mechanical responses of the protectors to a range of applied impacts were also examined. The vertical acceleration-time and force-displacement histories of a projectile during surface contact with a test manikin fitted with each protector were analyzed using a drop test methodology.

For clarity in this chapter, results and discussion of the physiological, psychological and agility data derived from human subjects will be presented first. The results and discussion of the off-the-body impact testing will conclude the chapter.

RESULTS: PHYSIOLOGICAL, PSYCHOLOGICAL AND AGILITY DATA

Metabolic Data

Due to the light weights of the protectors relative to body weight and their positioning on the torso rather than the limbs, protector wear was not expected to significantly increase oxygen consumption during the submaximal exercise protocol (Cureton et al., 1978). The maximal aerobic capacities of the 10 subjects and the treadmill speed representing a workload of approximately 70% of the maximal value for each subject are shown in Table 8.

The VO_2 values from minutes 9-10, 14-15, 19-20, 24-25, and 29-30 of the 30 minute submaximal treadmill run were averaged for each subject and used for analysis. The individual and group values for each experimental condition are shown in Table 9.

When group VO_2 means for each condition were examined, it was evident that a small, gradual upward drift in oxygen consumption occurred in all conditions over the 30 minutes of the exercise protocol (Figure 11). Analysis of the data indicated a significant difference between minute 5 and minute 30 mean values for most conditions, but few differences among other data points.

As hypothesized, protector wear did not significantly increase oxygen consumption above control values (Table 10). In addition, there were no significant differences in VO_2 values among the four protectors tested.

Table 8

Subjects' Maximal Aerobic Capacities and Treadmill Speeds

Subject	VO2max ($ml \cdot kg^{-1} \cdot min^{-1}$)	Treadmill Speed (mph)
1	54.5	6.50
2	49.3	5.75
3	49.0	5.75
4	55.3	6.50
5	64.3	7.25
6	61.7	7.25
7	58.5	7.00
8	68.1	7.25
9	50.7	6.00
10	57.8	6.75
Mean ± S.D.	**56.9** ± 6.4	**6.60** ± .60

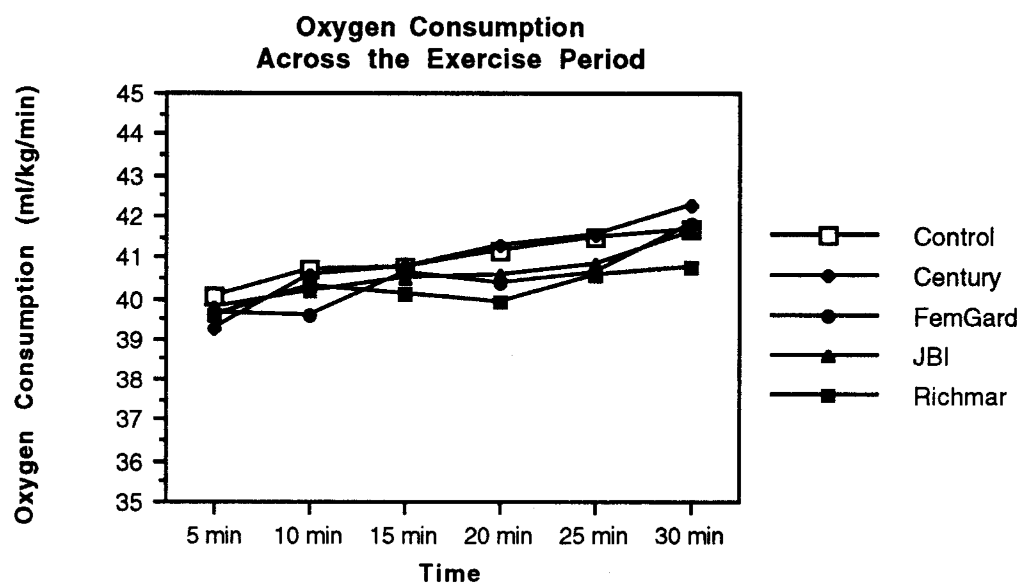


Figure 11. Mean Oxygen Consumption Values for All Subjects Across the Exercise Period

Table 9

Individual and Group VO_2's For the 5 Experimental Conditions ($ml \cdot kg^{-1} \cdot min^{-1}$): Means and Standard Deviations (SD)

Subject	No Protector	Century	FemGard	JBI	Richmar
1	**41.08** (.81)	**40.07** (1.05)	**37.68** (.88)	**38.77** (.65)	**39.64** (.61)
2	**34.95** (.72)	**35.16** (.93)	**34.70** (.46)	**36.57** (.39)	**35.64** (.97)
3	**37.10** (.99)	**37.91** (.75)	**37.49** (.71)	**36.62** (.38)	**36.81** (.39)
4	**44.83** (.40)	**41.60** (.57)	**40.12** (.67)	**44.29** (.62)	**41.37** (.65)
5	**45.25** (.60)	**47.68** (.50)	**48.42** (1.99)	**44.06** (.77)	**44.60** (.50)
6	**42.67** (.70)	**46.65** (1.14)	**44.06** (.46)	**43.37** (.56)	**41.16** (.70)
7	**41.52** (.44)	**40.53** (.49)	**40.80** (1.87)	**40.74** (.97)	**40.75** (.50)
8	**49.46** (1.16)	**48.78** (1.40)	**48.24** (1.53)	**48.82** (1.23)	**48.61** (1.61)
9	**36.12** (.92)	**36.09** (1.11)	**36.99** (1.33)	**36.49** (1.57)	**36.35** (.70)
10	**38.44** (1.89)	**38.34** (1.32)	**37.49** (1.48)	**37.53** (.59)	**38.33** (.43)
Group Mean & SD	**41.14** (4.44)	**41.28** (4.86)	**40.58** (4.79)	**40.73** (4.25)	**40.36** (3.95)

Table 10

ANOVA Repeated Measures Summary Results: Oxygen Consumption (VO_2)

Source	df	SS	MS	F	p level
Treatments	4	5.527	1.382	.922	.462
Blocks	9	845.211	93.912		
Error	36	53.972	1.499		
Total	49	904.71			

Local Skin Temperature Data

Because of the occlusive and insulative characteristics of the protectors tested, local skin temperatures at the skin's surface inferior to the protectors and temperature differentials between the skin and outer surface of the protectors were expected to be significantly greater than those of the control condition at the end of the exercise period and during the post-exercise rest period. Skin temperature was monitored at two sites, and additionally, the temperature of the outer surface of the protector was measured directly exterior to the two skin sites. The temperature differential between the skin's surface and the protector's surface was calculated by subtracting the skin temperature from the protector temperature as a measure of the insulative characteristics of the protector. Data were collected both during exercise and during the post-exercise rest period. Temperatures were recorded to the closest 0.1°C, and the value observed at each site at minutes 29-30 of the thirty minute run was used to evaluate temperature during exercise. Thermistor data obtained during minutes 4-5 of the five minute rest period were used for analysis of post-exercise temperature values.

Site 1 Local Skin Temperatures During Exercise. Mean skin temperature responses at center front for the group over the course of the protocol are shown in Figure 12. The control, Century and FemGard conditions tended to produce a general decline in temperature from baseline over the period of exercise, an increase during the cooldown period, and a small decline between the cooldown and rest periods. The JBI and Richmar conditions, on the other hand, tended to demonstrate a rise from baseline during the first 15 to 20 minutes, with the decline evidenced after 20 minutes. As with the other conditions, an increase in temperature occurred during cooldown, followed by a small decline in the rest period.

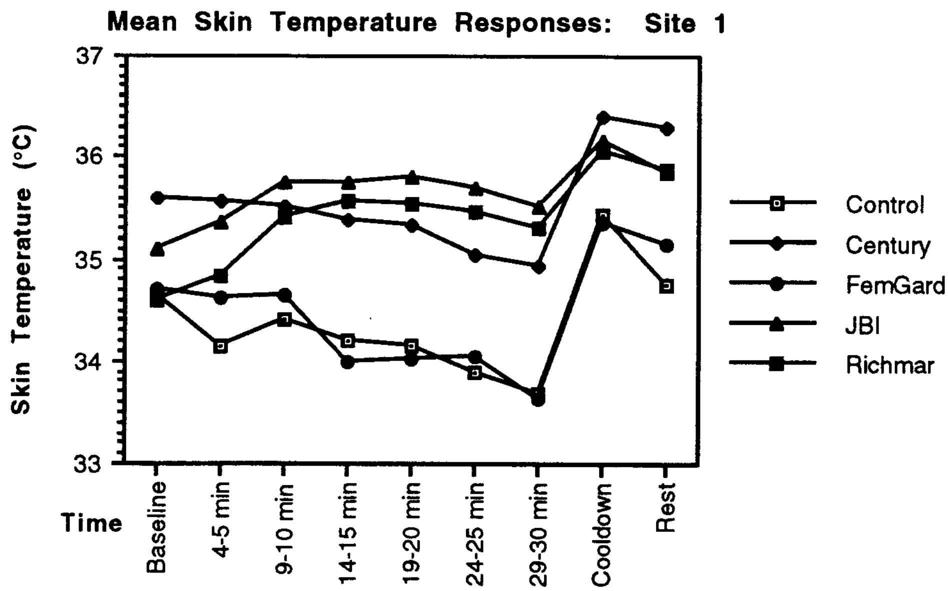


Figure 12. Site 1 Mean Local Skin Temperature Values Across Time

Significant differences in local skin temperature at Site 1 (center front) during the exercise period were found among the five experimental conditions, $F\,(4, 28) = 8.43, p < .0001$, as shown in Table 11. Analysis of pairwise differences (Table 12) indicated that JBI and Richmar temperatures were significantly higher than those of the control and FemGard conditions.

Table 11

ANOVA Repeated Measures Summary Results: Site 1 Local Skin Temperature (Exercise)

Source	df	SS	MS	F	p level
Treatments	4	36.899	9.225	8.43	.0001
Blocks	7	29.711	4.244		
Error	28	30.629	1.094		
Total	39	97.239			

Note: 2 cases deleted with missing values.

Table 12

Analysis of Pairwise Differences (Scheffé): Site 1 Local Skin Temperature, °C (Exercise)

Style	FemGard	No Protector	Century	JBI	Richmar
Mean (S.D.)	33.26 (1.80)	33.69 (1.49)	34.94 (1.08)	35.56 (1.30)	35.58 (.55)

Note. Means underscored by the same line not significantly different at $p < .05$.

Site 2 Local Skin Temperature During Exercise. Mean skin temperature responses at the base of the left breast for the group over the course of the protocol are shown in Figure 13. The control and JBI conditions tended to produce a short decline in temperature from baseline during the first 5 minutes of exercise, an increase through minutes 9-10, a general decline

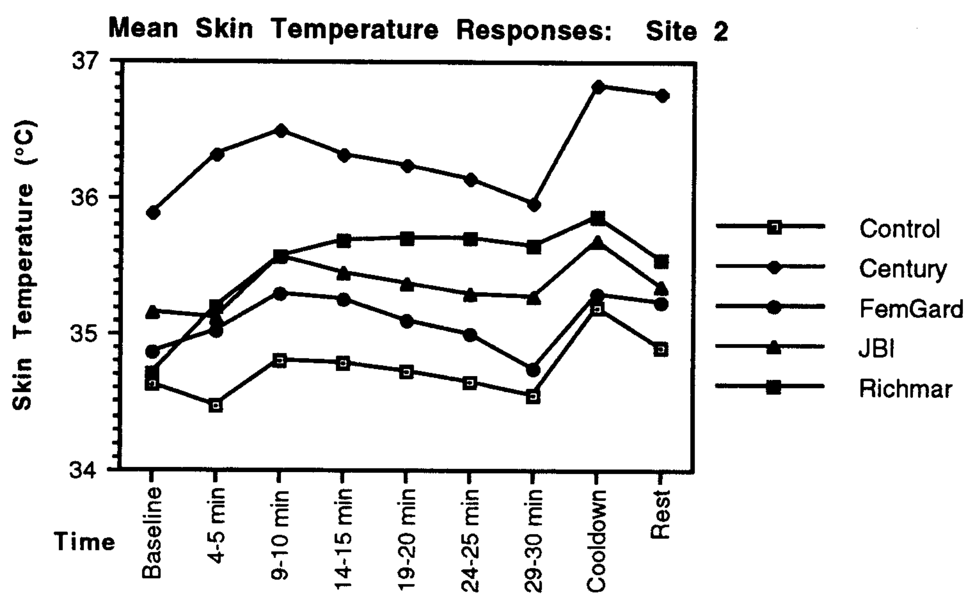


Figure 13. Site 2 Mean Local Skin Temperature Values Across Time

during the remainder of the exercise period, a rise during cooldown, and a decline between the cooldown and rest periods. The Century, FemGard and Richmar conditions, on the other hand, tended to demonstrate a rise from baseline during the first 10 minutes, followed by a gradual decline during the remainder of the exercise period. As with the other conditions, an increase in temperature occurred during cooldown, followed by a small decline in the rest period.

Significant differences in temperature were identified at Site 2 (the base of the left breast) at minutes 29-30 of the exercise period, $F\ (4, 36) = 11.30, p < .0001$ (Table 13). Analysis of significant pairwise differences showed that Century and Richmar temperatures were higher than those for the control and FemGard conditions (Table 14).

Table 13

ANOVA Repeated Measures Summary Results: Site 2 Local Skin Temperature (Exercise)

Source	df	SS	MS	F	p level
Treatments	4	13.209	3.302	11.30	.0001
Blocks	9	19.914	2.213		
Error	36	10.519	.292		
Total	49	43.642			

Table 14

Analysis of Pairwise Differences (Scheffé): Site 2 Local Skin Temperature, °C (Exercise)

Style	No Protector	FemGard	JBI	Richmar	Century
Mean (S.D.)	34.54 (.69)	34.86(.80)	35.28 (.75)	35.65 (.52)	35.96 (1.20)

Note. Means underscored by the same line not significantly different at $p < .05$.

Site 1 Temperature Differential During Exercise. Significant differences were found among skin/protector temperature differentials at center front, $F(4, 28) = 9.36, p < .0001$, (Table 15). The Century and JBI differentials were significantly larger than those of the control, FemGard and Richmar conditions (Table 16).

Table 15

ANOVA Repeated Measures Summary Results: Site 1 Temperature Differential (Exercise)

Source	df	SS	MS	F	p level
Treatments	4	66.411	16.603	9.36	.0001
Blocks	7	66.4	9.486		
Error	28	49.693	1.775		
Total	39	182.504			

Note: 2 cases deleted with missing values.

Table 16

Analysis of Pairwise Differences (Scheffé): Site 1 Temperature Differential, °C (Exercise)

Style	FemGard	Richmar	No Protector	JBI	Century
Mean (S.D.)	**5.84** (2.34)	**6.34** (1.52)	**6.38** (1.77)	**8.60** (1.34)	**8.95** (1.97)

Note. Means underscored by the same line not significantly different at $p < .05$.

Site 2 Temperature Differential During Exercise. Temperature differentials at the base of the left breast also manifest significant differences, $F(4, 36) = 48.15, p < .0001$ (Table 17). The Century differential was significantly larger than those of the other four experimental conditions, and the FemGard differential was larger than that of the control condition (Table 18).

Table 17

ANOVA Repeated Measures Summary Results: Site 2 Temperature Differential (Exercise)

Source	df	SS	MS	F	p level
Treatments	4	238.097	59.524	48.15	.0001
Blocks	9	22.621	2.513		
Error	36	44.503	1.236		
Total	49	305.221			

Table 18

Analysis of Pairwise Differences (Scheffé): Site 2 Temperature Differential, °C (Exercise)

Style	No Protector	JBI	Richmar	FemGard	Century
Mean (S.D.)	**4.47**(.75)	**5.39** (1.01)	**5.51** (1.01)	**6.59** (1.43)	**10.68** (1.65)

Note. Means underscored by the same line not significantly different at $p < .05$.

Site 1 Local Skin Temperature Post-exercise. The significant differences in skin temperature, $F(4, 32) = 5.61$, $p < .0016$, identified at center front during the post-exercise rest period following cooldown varied somewhat from those obtained during the exercise period (Tables 19 and 20). While the JBI and Richmar protectors produced higher temperatures than the control and FemGard conditions during exercise, they were not significantly warmer during the post-exercise rest period. The Century, which had not been warmer than the control and FemGard conditions during the exercise period, was significantly warmer than these two conditions in the post-exercise rest period.

Table 19

ANOVA Repeated Measures Summary Results: Site 1 Local Skin Temperature, °C (Post-exercise)

Source	df	SS	MS	F	p level
Treatments	4	10.989	2.747	5.61	.0016
Blocks	8	9.626	1.203		
Error	32	15.683	.4901		
Total	44	36.298			

Note: 1 case deleted with missing values.

Table 20

Analysis of Pairwise Differences (Scheffé): Site 1 Local Skin Temperature, °C (Post-exercise)

Style	No Protector	FemGard	Richmar	JBI	Century
Mean (S.D.)	35.10 (.98)	35.13 (1.26)	35.87 (.37)	35.90 (.65)	36.39 (.53)

Note. Means underscored by the same line not significantly different at $p < .05$.

Site 2 Local Skin Temperature Post-exercise. Post-exercise temperature values at the base of the left breast varied significantly among the experimental conditions, F (4, 36) = 16.52, $p < .0001$ (Tables 21 and 22), and relationships were somewhat different from those of the exercise period. The Century protector produced significantly higher temperatures than all other experimental conditions. The Richmar, which had produced higher temperatures than the control and FemGard conditions during exercise, was not significantly hotter than any other conditions during the post-exercise period.

Table 21

ANOVA Repeated Measures Summary Results: Site 2 Local Skin Temperature, °C (Post-exercise)

Source	df	SS	MS	F	p level
Treatments	4	20.287	5.071	16.52	.0001
Blocks	9	16.282	1.809		
Error	36	11.053	.307		
Total	49	47.622			

Table 22

Analysis of Pairwise Differences (Scheffé): Site 2 Local Skin Temperature, °C (Post-exercise)

Style	No Protector	FemGard	JBI	Richmar	Century
Mean (S.D.)	34.90 (1.03)	35.23 (.68)	35.35 (.95)	35.55 (.58)	36.76 (.53)

Note. Means underscored by the same line not significantly different at $p < .05$.

Site 1 Temperature Differential Post-exercise. Significant differences were found in the skin/protector temperature differential at center front during the post-exercise period, F (4, 28) = 17.90, $p < .0001$ (Table 23). As during the exercise period, the Century differential was significantly larger than those of the control, FemGard and Richmar conditions and the JBI differential was larger than those of the FemGard and Richmar conditions (Table 24). During the rest period, however, the JBI differential was not significantly larger than that of the control condition, as it had been during exercise.

Table 23

ANOVA Repeated Measures Summary Results: Site 1 Temperature Differential (Post-exercise)

Source	df	SS	MS	F	p level
Treatments	4	167.393	41.848	17.90	.0001
Blocks	7	20.836	2.977		
Error	28	65.452	2.338		
Total	39	253.68			

Note: 2 cases deleted with missing values.

Table 24

Analysis of Pairwise Differences (Scheffé): Site 1 Temperature Differential, °C (Post-exercise)

Style	Richmar	FemGard	No Protector	JBI	Century
Mean (S.D.)	4.73 (1.79)	5.06 (1.71)	6.48 (1.46)	7.94 (.81)	10.30 (1.85)

Note. Means underscored by the same line not significantly different at $p < .05$.

Site 2 Temperature Differential Post-exercise. Significant differences in temperature differentials at the base of the left breast during the post-exercise were similar to those found during the exercise period, F (4, 36) = 54.61, $p < .0001$) (Table 25). At this location, the Century differential was significantly larger than those of the other four experimental conditions (Table 26). While the FemGard temperature differential had been significantly larger than that of the control condition during the exercise period, this was not true for the post-exercise period. There were no other significant differences in post-exercise temperature differentials at this site.

Table 25

ANOVA Repeated Measures Summary Results: Site 2 Temperature Differential (Post-exercise)

Source	df	SS	MS	F	p level
Treatments	4	404.491	101.123	54.61	.0001
Blocks	9	22.279	2.476		
Error	36	66.669	1.852		
Total	49	493.439			

Table 26

Analysis of Pairwise Differences (Scheffé): Site 2 Temperature Differential, °C (Post-exercise)

Style	No Protector	JBI	Richmar	FemGard	Century
Mean (S.D.)	2.49 (.72)	3.45 (.89)	3.75 (1.34)	3.89 (1.31)	10.40 (2.24)

Note. Means underscored by the same line not significantly different at $p < .05$.

Perceived Comfort Data

Due to the occlusive, insulative and somewhat rigid characteristics of the protectors, it was expected that protector wear during the exercise and post-exercise periods would result in higher ratings of local thermal sensation and local skin wettedness, and in lower ratings of general comfort sensation when compared to the control (no protector) condition. Differences in the design and fabrication of the various protectors were also expected to elicit differences in perceptual data among the protectors. Data obtained during minutes 29-30 of the thirty minute submaximal treadmill run were used for analysis of perceptual comfort for the exercise period. Data recorded during minutes 4-5 of the five minute rest period were used in the analysis of post-exercise perceptions.

Perceived Local Skin Temperature During Exercise. Statistical analysis indicated a significant difference among conditions in perceived local skin temperature at minutes 29-30 of the exercise protocol, F (4, 36) = 3.18, $p <$ .024, (Table 27). Subsequent pairwise comparisons revealed only one difference among the five experimental conditions: the Century protector was perceived as significantly hotter than the JBI protector during exercise (Table 28). No protectors were perceived as being hotter than the control (no protector) condition.

Table 27

ANOVA Repeated Measures Summary Results: Perceived Local Skin Temperature (Exercise)

Source	df	SS	MS	F	p level
Treatments	4	4.6	1.15	3.18	.024
Blocks	9	36.4	4.04		
Error	36	13.0	.361		
Total	49	54.0			

Table 28

Analysis of Pairwise Differences (Scheffé): Perceived Local Skin Temperature (Exercise)

Style	JBI	No Protector	FemGard	Richmar	Century
Mean (S.D.)	5.6 (1.51)	5.8 (.92)	6.0 (.82)	6.1 (1.10)	6.5 (.71)

Note. Means underscored by the same line not significantly different at $p < .05$.

Perceived Local Skin Wettedness During Exercise. While the ANOVA statistical test yielded a significant result, $F(4, 36) = 3.08, p < .028$, (Table 29), subsequent pairwise comparisons failed to yield any specific significant differences in perceived wettedness among experimental conditions at minutes 29-30 of the exercise protocol (Table 30). While more liberal pairwise comparison procedures did identify significant differences among conditions, the more conservative Scheffé *F* test did not.

Table 29

ANOVA Repeated Measures Summary Results: Perceived Local Skin Wettedness (Exercise)

Source	df	SS	MS	F	p level
Treatments	4	9.88	2.47	3.08	.028
Blocks	9	55.28	6.142		
Error	36	28.92	.803		
Total	49	54.0			

Table 30

Analysis of Pairwise Differences (Scheffé): Perceived Local Skin Wettedness (Exercise)

Style	FemGard	JBI	No Protector	Century	Richmar
Mean (S.D.)	**5.3** (1.77)	**5.4** (1.43)	**5.4** (1.58)	**6.1** (.99)	**6.4** (.85)

Note. Means underscored by the same line not significantly different at $p < .05$.

Perceived Overall Comfort During Exercise. Differences in perceived comfort among conditions at minutes 29-30 of exercise were significant but few, $F(4, 36) = 6.37, p < .0006$, (Tables 31 and 32). The control (no protector) condition was rated as significantly more comfortable than the Century and Richmar conditions. There were no other differences in overall comfort among conditions during exercise.

Table 31

Repeated Measures Summary Results: Perceived Overall Comfort (Exercise)

Source	df	SS	MS	F	p level
Treatments	4	35.32	8.83	6.37	.0006
Blocks	9	28.72	3.20		
Error	36	49.88	1.386		
Total	49	113.92			

Table 32

Analysis of Pairwise Differences (Scheffé): Perceived Overall Comfort (Exercise)

Style	No Protector	JBI	FemGard	Richmar	Century
Mean (S.D.)	1.8 (.79)	2.4 (1.08)	3.2 (1.14)	3.7 (1.16)	4.1 (2.08)

Note. Means underscored by the same line not significantly different at $p < .05$.

Perceived Local Skin Temperature Post-exercise. Significant differences in temperature perceptions during the post-exercise rest period, F (4, 36) = 5.32, $p < .0018$, were similar to those of the exercise period (Tables 31 and 32). The Century protector, in addition to feeling hotter than the JBI protector as it had under exercise conditions, was also perceived as hotter than the FemGard and control conditions during the post-exercise rest period. There were no other significant differences in perceived temperature during the rest period.

Table 33

ANOVA Repeated Measures Summary Results: Perceived Local Skin Temperature (Post-exercise)

Source	df	SS	MS	F	p level
Treatments	4	12.48	3.12	5.32	.0018
Blocks	9	48.44	5.431		
Error	36	21.12	.587		
Total	49	82.48			

Table 34

Analysis of Pairwise Differences (Scheffé): Perceived Local Skin Temperature (Post-exercise)

Style	JBI	FemGard	No Protector	Richmar	Century
Mean (S.D.)	4.1 (1.37)	4.3 (1.16)	4.3 (1.42)	4.4 (1.26)	5.5 (.97)

Note. Means underscored by the same line not significantly different at $p < .05$.

Perceived Local Skin Wettedness Post-exercise. As in the exercise period, whereas the analysis of variance procedure yielded a significant result, F (4, 36) = 3.32, $p < .0204$ (Table 35), subsequent pairwise comparisons failed to yield any significant differences among specific conditions during the post-exercise rest period (Table 36).

Table 35

ANOVA Repeated Measures Summary Results: Perceived Local Skin Wettedness (Post-exercise)

Source	df	SS	MS	F	p level
Treatments	4	8.2	2.05	3.32	.0204
Blocks	9	98.1	10.9		
Error	36	22.2	.617		
Total	49	128.5			

Table 36

Analysis of Pairwise Differences (Scheffé): Perceived Local Skin Wettedness (Post-exercise)

Style	FemGard	No Protector	Richmar	JBI	Century
Mean (S.D.)	4.0 (1.25)	4.5 (1.84)	4.9 (1.60)	5.0 (1.76)	5.1 (1.66)

Note. Means underscored by the same line not significantly different at $p < .05$.

Perceived Overall Comfort Post-exercise. Significant differences in perceptions of overall comfort during the rest period were scarce. Although a significant F $[(4, 36) = 3.08, p < .028]$ was found, only one significant pairwise comparison was identified in post hoc analysis (Tables 37 and 38). The control condition was perceived as significantly more comfortable than the Century condition during the post-exercise period.

Table 37

ANOVA Repeated Measures Summary Results: Perceived Overall Comfort (Post-exercise)

Source	df	SS	MS	F	p level
Treatments	4	9.48	2.37	3.08	.028
Blocks	9	18.48	2.053		
Error	36	27.72	.77		
Total	49	55.68			

Table 38

Analysis of Pairwise Differences (Scheffé): Perceived Overall Comfort (Post-exercise)

Style	No Protector	JBI	FemGard	Richmar	Century
Mean (S.D.)	1.6 (.70)	1.9 (.99)	2.0 (.82)	2.0 (.67)	2.9 (1.60)

Note. Means underscored by the same line not significantly different at $p < .05$.

Agility Data

The effect of protector wear on general agility was expected to vary among experimental conditions due to differences in weight, bulk, coverage and stiffness of the various protectors. Analysis of agility course times revealed a significant difference among conditions, F (4, 36) = 4.02, p < .0085 (Table 39). Subsequent pairwise comparisons indicated that agility course times for the Richmar condition were significantly faster than those of the control condition (Table 40). No other significant differences among conditions were found.

Table 39

ANOVA Repeated Measures Summary Results: Agility Course Times

Source	df	SS	MS	F	p level
Treatments	4	3.719	.930	4.02	.0085
Blocks	9	43.897	4.877		
Error	36	8.329	.2314		
Total	49	55.945			

Table 40

Analysis of Pairwise Differences (Scheffé): Agility Course Times (sec)

Style	Richmar	FemGard	Century	JBI	No Protector
Mean (S.D.)	20.82 (1.02)	20.90 (1.14)	21.15 (1.04)	21.33 (1.17)	21.56 (.99)

Note. Means underscored by the same line not significantly different at $p < .05$.

DISCUSSION: PHYSIOLOGICAL, PSYCHOLOGICAL AND AGILITY DATA

Metabolic Data

Due to the light weights of the protectors relative to body weight, and their positioning on the torso rather than the limbs, it was hypothesized that protector wear would not create a significantly greater energy demand than the no-protector condition (Cureton et al., 1978; Goldman & Iampietro, 1962). In this case, the heaviest (Century) protector's mass of

0.30 kg represented less than 0.5% of the subjects' average body mass. Thus, the absence of significant differences between the control and protector conditions was not surprising.

Within-subject mean VO_2 values (Table 9) for the same rate of submaximal running across the five experimental conditions varied from 2.3% to 11.8% over the period of testing, while mean VO_2 values across the group varied 2.2%. These values are consistent with the range of intraindividual variability in running economy of 2% to 11% previously reported for day-to-day treadmill running in which daily conditions were held constant (Morgan, Martin & Krahenbuhl, 1989). Accordingly, there is no evidence to suggest that the observed variability in economy in this study was related to protector wear rather than to normal day-to-day intraindividual variation. In fact, the findings imply that the female athlete can enjoy the benefits of breast protection without incurring a higher metabolic cost for a given submaximal activity.

Local Skin Temperature Data

Due to the occlusive and insulative characteristics of the various protectors examined in this study, it was hypothesized that protector wear would significantly increase local skin temperature in the chest/breast area above that of the control (no protector) condition. Skin temperature was monitored at two sites during both exercise and rest, and the temperature differential between the skin and outer protector surface was established for all conditions. Indeed, a number of significant differences in thermal values were found between the control and certain protector conditions, as well as among the different styles of protectors. This section will discuss temperatures and differentials at Site 1 and Site 2 during exercise, followed by temperatures and differentials at both sites during the post-exercise period.

Site 1 Skin Temperatures During Exercise. Two protectors, the JBI and Richmar, produced significantly higher temperatures at this center front site than the no-protector and FemGard conditions. Both the JBI and the Richmar protectors utilize rigid, impermeable polyethylene material and fit closely to the body at center front. In addition, the layers of fabric and open-cell foam used in this area of the JBI to cushion the edges of the overlapping plastic cups provide additional insulation against heat loss. The Century, which was not significantly warmer than the control and JBI conditions, is cut lower at the neckline and stands somewhat away from the torso, providing greater opportunity for "chimney" and "bellows" ventilation, particularly when combined with the rotation of the chest during running. The FemGard has no material other than a few thin elastic cords in this center front area, so would be expected to perform in much the same manner as the control condition.

Site 2 Skin Temperatures During Exercise. Local skin temperature relationships at Site 2 at the base of the left breast varied somewhat from those observed at Site 1. The Century and Richmar protectors produced higher temperatures at this location, being significantly warmer than the control and FemGard. The Century and Richmar protectors both extend several inches down the chest below the base of the breast to provide additional protection for the ribs, while the FemGard's rigid cups terminate just inferior to the bottom of the breast and the thermistor. The greater body coverage of the Century and Richmar, along with the insulative closed-cell foam construction of the Century, most likely contributed to the higher skin temperatures produced at this site.

Site 1 Temperature Differential During Exercise. The differential between the temperature at the surface of the skin and the outer surface of the protector (the outer surface of the Olga's Christina sports bra in the control condition) was calculated to provide a measure of the insulative characteristics of the protector. The larger the difference between the two temperatures, the more effective an insulator the protector was considered to be. The size of the differential was related to the actual temperature on the skin's surface, the materials from which the protector was constructed, and the closeness of fit of the protector.

At center front, both the Century and JBI protectors produced significantly larger differentials than those of the control, FemGard, and Richmar conditions. The first contributing factor to the larger differentials is that the JBI and Century skin temperatures at this site were at the higher end of the spectrum of all conditions while the FemGard and control conditions were at the lower end. Higher skin temperatures relative to reasonably constant ambient conditions would tend to result in larger differentials. However, considering that the Richmar skin temperature at this site was slightly higher than either the JBI or Century skin temperatures, it is apparent that design and fit characteristics also contributed to the observed differentials.

The Century protector is constructed of a closed-cell polyurethane foam, the type of material often used in pads placed beneath sleeping bags to minimize conductive heat loss to the ground. At center front, the JBI protector is composed of overlapping high density polyethylene cup extensions to protect the sternum, and multiple layers of fabric and open-cell polyethylene foam to guard against potential abrasion from the cups. Hence it is not surprising that both protectors constitute fairly efficient mechanisms against conductive heat loss. The Richmar protector, even though extremely occlusive at center front, has no foam insulation, is composed of only one layer of polyethylene, has close contact with the body, and thus could conceivably allow greater conductive heat loss. Lacking occlusive or insulative material at center front, the FemGard's temperature differential was, as expected, similar to that of the control condition.

Site 2 Temperature Differential During Exercise. The temperature differential data collected at the base of the left breast varied somewhat from that of the center front. At this site, the Century protector produced a significantly larger differential than the four other experimental conditions, most likely due to the insulative efficiency of its closed-cell foam fabrication which elevated the Century's local skin temperature at this site. The FemGard's temperature differential was significantly larger than that of the control condition. This is a bit surprising, considering that the FemGard's local skin temperature at this site was lower than those of the JBI and Richmar protectors, and was only marginally higher (0.32°C) than that of the control condition. For a given set of ambient conditions, one would generally anticipate larger differentials to be associated with higher local skin temperatures. There were no other significant differences at this site.

Unlike the findings at Site 1, the JBI's differential was not significantly greater than those of the control, FemGard and Richmar conditions at this anatomical location. This was perhaps due to the presence of fewer layers of plastic and fabric exterior to the thermistor for the JBI at this site as compared to center front, and to the fact that the thermistor itself was positioned much closer to an edge of the occlusive plastic material at this site, increasing the likelihood that the heat produced in this area could escape from beneath the protector.

Site 1 Skin Temperature Post-exercise. The post-exercise rest period produced a somewhat different pattern of significant temperature differences. The JBI and Richmar protectors did not induce temperatures significantly higher than the FemGard and control conditions as they had during exercise. The Century protector, on the other hand, performed in the opposite manner. Unlike the results observed for the exercise period, the Century significantly raised skin temperatures above those of the control and FemGard conditions during the rest period. It is possible that during this rest period, when metabolic demands have fallen dramatically but when a great deal of heat must still be dissipated as the subject is sitting quietly, that the insulative effects of foam materials such as that found in the Century protector are particularly noticeable. The Richmar protector in particular, lacking any foam or fabric covering, may have been more capable of facilitating heat loss through conductive mechanisms, resulting in lower skin temperatures.

Site 2 Skin Temperature Post-exercise. Temperature values at this site during the rest period differed from exercise temperature values in much the same manner as at Site 1. The Richmar was not significantly warmer than any other condition as it had been during exercise, and the Century was significantly warmer than even more conditions than it had been during exercise. As discussed in the preceding paragraph, this effect may be due to the closed-cell foam construction of the Century protector, which is an extremely effective deterrent to the passage of heat.

The Site 1 and Site 2 temperature values observed during the post-exercise rest period were more highly correlated than those observed during the exercise period, r =.63 for the rest period, r = .41 for the exercise period. The mean temperature difference for the two sites (Site 1 - Site 2) during the rest period was 0.09°C for the rest period compared to -0.67°C for the exercise period. Hence, during the rest period greater similarities were seen in the patterns of temperature relationships for the two sites. Rotation of the torso and displacement of elastic breast tissue contributing to "bellows" ventilation at center front while running, coupled with greater variations in materials, construction and closeness of fit of the protectors at this site may have contributed to the greater extent of differences observed between the two sites during exercise.

Site 1 Temperature Differential Post-exercise. Temperature differential relationships at this location during the rest period were similar to those found during the exercise period. The Century and JBI protectors produced significantly larger differentials than the FemGard and Richmar protectors and the control condition. As discussed above regarding the exercise period, the insulative materials and layers found in the Century protector resulting in higher local skin temperatures at center front and substantial resistance to the flow of heat away from the body were most likely responsible for the larger size of its differential. While larger differentials are generally associated with higher local skin temperatures, the JBI protector did not produce significantly higher skin temperatures than the FemGard, Richmar and control conditions at Site 1. A larger differential associated with a lower local skin temperature could indicate that while heat was somehow escaping from inside the protector, it was not leaving through the protector directly exterior to the site of the thermistor but rather at some other location.

Site 2 Temperature Differential Post-exercise. Temperature differential relationships at the base of the left breast post-exercise paralleled those observed during the exercise period, with the exception that the FemGard's differential was not significantly greater than that of the control condition. The Century's differential was significantly larger than those of all other conditions. Again, this is likely due to the effectiveness of its closed-cell foam in impeding heat loss and sustaining high local skin temperatures, as temperature differential relationships at this site were identical to skin temperature relationships.

Perceived Comfort Data

Perceived Local Skin Temperature During Exercise. Relationships among perceived temperature ratings in the area of the chest covered by the chest/breast protectors varied markedly from those of the temperature values measured by thermistors at Site 1 (center front). Analysis of the perceptual data revealed only one significant pairwise difference: the Century protector was perceived to be significantly hotter than the JBI during exercise. In contrast, thermistor values for the JBI and Richmar protectors were significantly higher than those of the control and FemGard conditions, and Century temperatures were positioned in the middle of the group. It is possible that statistically significant differences in skin temperature are not always of practical significance to the exercising athlete. It is also possible that subjects could have incorporated perceptual input from areas of the the body other than the specified site.

Objective temperature values obtained at Site 2 appeared more similar to perceptual data, in that Century temperatures were the highest of all conditions, significantly more so than those of the control and FemGard conditions. However, correlations for all conditions between perceived local skin temperature and measured skin temperature at both sites during exercise were extremely low, $r = -.033$ for Site 1, $r = .029$ for Site 2. Considering that perceptual judgments pass through a filter of past experiences (Pontrelli, 1977), it is possible that the overall bulkiness and sticky vinyl surface of the Century protector may have been strongly associated with previous bouts of thermal discomfort in the mind of the wearer, prompting higher ratings of thermal sensation not strictly related to the immediate physiological condition.

Perceived Local Skin Wettedness During Exercise. Given the highly occlusive nature of all protectors tested, the lack of any significant differences in perceived local skin wettedness among the protectors was not surprising. Ratings for all conditions clustered around the descriptor "wet." The intensity of the workload and warm environmental conditions in combination with the impermeability of all protectors to the transfer of liquid or gaseous moisture ensured high humidity levels at the skin/bra interface. What was unexpected is the lack of differences in perceived skin wettedness between the protectors and the control condition, which fails to support the hypothesized relationship.

Subjects in the control condition wore a lightweight sports bra consisting of two thin layers of 46% cotton/46% polyester/8% lycra jersey, topped by a cropped mesh knit singlet of 50% cotton/50% polyester. This ensemble is representative of activewear fabrics and styles that are recommended in exercise publications for strenuous activity in warm weather conditions, and would be expected to be appropriate for the sweat rates induced by this protocol. It is possible, however, that the workload and environmental conditions were sufficiently challenging to induce high sweat rates and high fabric moisture content next to the skin in all conditions, including the control. While the cotton content of the sports bra would be efficient in collecting sweat from the skin's surface, it would not be particularly effective in moving that moisture further away from the skin even in the control condition. This is particularly true in treadmill running where the normal ventilation across the torso associated with overground running was not present.

It was suspected that perhaps the JBI protector would earn lower ratings of perceived local skin wettedness because its inner cup is constructed of CoolMax®, a fiber specifically engineered to transport moisture away from the skin's surface and promote a sensation of dryness. This effect, however, was not seen. As discussed above, it may be that the exercise conditions combined with the occlusive outer layer of the JBI protector presented a moisture challenge that not even an advanced fiber such as CoolMax® could overcome. This notion was informally confirmed by the "soaking wet" condition of all bras and protector inner surfaces when they were returned to the researcher by the subject after each day's protocol.

It should be noted, however, that high levels of sweat secretion are not necessarily associated with discomfort during exercise. In fact, the more strenuous the workload, the greater the sweat rate required for comfort (Gagge, 1981). There is, however, the further assumption that the sweat thus produced will not be significantly impeded from evaporating from the skin and clothing, thus providing evaporative cooling and greater thermal comfort (Fanger, 1973). The previous work of Goldman

(1981) on impermeable garments of varying lengths would suggest that, given the relatively small percentage of the total body surface covered by the protectors in this study, local skin wettedness sensations may have affected tactile elements of comfort but that overall sweat evaporation rates and thermal regulation were not excessively impaired.

Perceived Overall Comfort During Exercise. The General Comfort Sensation scale was used in this study to provide a more complete, global description of the comfort of the various protectors. Due to the occlusive, insulative, and somewhat rigid characteristics of the protectors, it was expected that their use would lower general comfort sensation ratings. During exercise, the FemGard and JBI protectors were evaluated to be similar to the control condition on general comfort in the chest/breast region while the Century and Richmar protectors were judged to be significantly less comfortable. Several characteristics may have contributed to these findings. Both the Century and Richmar produced significantly higher measured skin temperatures than the control and FemGard conditions at Site 2 during exercise. In addition, the Century and Richmar protectors were larger and covered more of the skin's surface area with occlusive materials than the other protectors. The Century protector's foam construction was bulkier and more insulative. Also, the bare edges of the rigid plastic material along all borders of the Richmar were a potential source of abrasion; in fact several subjects experienced minor skin trauma to the torso several inches below the breasts from repetitive contact with the lower edge of this protector. In practice, this problem could probably be eliminated by wearing a light singlet or T-shirt underneath the protector. While the inclusion of an additional clothing layer might further increase thermal discomfort, its ability to prevent bleeding abrasions would certainly enhance overall comfort.

It was encouraging to observe that two of the protectors, the FemGard and the JBI, were not perceived to be significantly more uncomfortable than the no-protector condition. This finding suggests that it is possible for the female athlete to enjoy the benefits of breast protection without sacrificing comfort.

It must be noted that these comfort ratings were derived from a protocol of treadmill running at a submaximal pace. No arm movements requiring significant joint range of motion were involved, no sudden changes in speed or direction were performed, and no sports-related impacts occurred during the exercise period. During actual contact sport participation, issues of whether or not a protector stays correctly positioned on the body, interferes with lateral arm flexion, or painfully contacts the body during a collision could also factor into general comfort ratings. Hence, these comfort ratings must be interpreted with this limitation in mind.

Perceived Local Skin Temperature Post-exercise. Relationships among the perceived temperature ratings in the area of the chest covered by the chest/breast protectors during the post-exercise rest period generally reflected those of measured temperature values at both Site 1 and Site 2. Analysis of perceptual data revealed that the Century was perceived to be significantly warmer than the FemGard, JBI and control conditions. Thermistor data showed the Century to be significantly warmer than the control and FemGard conditions at Site 1, and warmer than all other conditions at Site 2 during the rest period. Considering that the Century is constructed of highly insulative material and that it generally produced higher temperatures during the rest period than the other protectors, it is not surprising that subjects reported a pattern of perceived thermal sensations similar to objective data.

Perceived Local Skin Wettedness Post-exercise. Relationships among perceived skin wettedness data during the rest period were similar to those found for the exercise period in that the Scheffé F test did not identify any significant pairwise differences. Mean wettedness ratings during the rest period were slightly lower than those of the exercise period, clustering around the "damp" side of "wet." As discussed above in reference to skin wettedness ratings during the exercise period, the experimental protocol produced a layer of wet fabric next to the skin in all conditions. As a result, it was unlikely that subjects would be able to discriminate among protectors on the basis of local skin wettedness sensations.

Perceived Overall Comfort Post-exercise. Fewer differences in overall comfort ratings were found during the post-exercise rest period as compared to the exercise period. During the rest period, only one significant pairwise comparison was identified, with the control condition being perceived as significantly more comfortable than the Century condition. The Richmar, which had been rated as significantly more uncomfortable than the no-protector condition during exercise, was not significantly different than the control during the rest period. Perhaps once body movement ceased, the aforementioned chafing of the torso by the Richmar also stopped. Mean overall comfort ratings for all conditions during the rest period were approximately one scale step closer to "comfortable" than those observed during the exercise period. These data do not support Morris et al.'s (1985) finding that perceived comfort differences among garments were more likely to emerge after cooldown rather than during exercise. However, differences in protocols may be partially responsible for the differences in findings, as Morris' subjects were wearing full warm-up suits and the cooldown period in her study consisted of ten minutes of active recovery at a walking speed of 3.5 mph rather than the five minutes of walking at 2 mph and five minutes of seated rest utilized in the present study.

Agility Data

Due to differences in weight, bulk, coverage and stiffness among the four protectors tested and between the protectors and the control condition, it was hypothesized that agility course times would vary among experimental conditions. However, prior to data collection there was a sense of uncertainty as to whether times for some protectors might be slower than the no-protector condition due to encumbrance and interference with movement, or whether the use of breast protection might encourage more aggressive movement on the agility course, resulting in faster times.

Examination of the mean agility course times revealed the following sequence from slowest to fastest times: 1) no-protector, 21.56 sec; 2) JBI, 21.33 sec; 3) Century, 21.15 sec; 4) FemGard, 20.9 sec; and 5) Richmar, 20.82 sec. While only the times for the no-protector and Richmar conditions were significantly different from each other, the trend for the no-protector times to be slower than those of all protector conditions suggests that protector wear may indeed foster feelings of invulnerability to discomfort and injury, and encourage more aggressive participation.

The agility course utilized in this study called for the subject to dive headfirst under an 18" horizontal bar, sliding along the floor on the chest in order to achieve a fast course time. When compared with the body movements required for other segments of the course, it would appear that failure to aggressively throw the body to the floor during this part of the protocol held perhaps the greatest potential for slowing overall course times. Of the four protectors tested, the Richmar is the most rigid and affords seamless protection across the breast area from upper sternum to lower ribs. It should not be surprising, then, that the course times associated with the use of this protector were the fastest. This finding suggests that the use of breast protection need not present a significant impediment to agility during sports performance, and that, in fact, a player can reduce the risk of breast injury while simultaneously enhancing aggressiveness.

RESULTS AND DISCUSSION: IMPACT DATA

Cushioning Properties

Due to the differences in their constituent materials, it was hypothesized that the four protectors would vary in their cushioning responses to applied impacts. Cushioning properties were assessed using a guided free-fall drop test apparatus employing missiles of three different masses (.56 kg, 1.14 kg, and 2.30 kg), each dropped from two different heights. A linear accelerometer was used to monitor the acceleration-time history of the impact and assess the shock attenuation properties of each protector. Further calculations were performed on acceleration data to yield force and displacement data for the evaluation of energy absorbency.

Shock Attenuation: Acceleration-time Data

Peak Acceleration. The maximum acceleration, or rate at which velocity changes with respect to time, encountered by a missile during impact with another object is one means of describing the shock attenuating characteristics of materials (ASTM, 1990). The lower the peak acceleration recorded, the more effectively the material is considered to attenuate the shock associated with the impact. Peak acceleration values for all experimental conditions are presented in Table 41 and Figure 14.

Across all conditions, the Richmar protector generally produced the highest accelerations and the Century protector the lowest, although there were a few exceptions to these trends for some test conditions. The material used in each protector and its mechanism for providing impact protection help explain these findings. The Richmar protector is fabricated of a continuous sheet of rigid material, while the Century represents the softest material of any of the protectors. Whereas the Richmar's polyethylene plate protects by posing a direct barrier between the body and the impact, the Century's closed-cell foam mediates the blow by spreading the change in momentum of the impacting object over a longer period of time.

FemGard and JBI peak acceleration values tended to be intermediate to the Century and Richmar values. The rigid plastic cups of these two protectors are thinner in gauge than that of the Richmar. These protectors are composed of two smaller, more mobile cups rather than one single plate of plastic. While the JBI protector incorporates a few areas of thin open-cell foam for tactile comfort, neither the FemGard or the JBI uses closed-cell foam as the Century does to mediate impact.

Table 41

Peak Acceleration Values (m/sec/sec): Means and Standard Deviations (SD)

Protector:	Century	FemGard	JBI	Richmar
Test Condition:				
.56 kg missile				
Low drop	**16.90** (.19)	**33.87** (.58)	**28.99** (.24)	**41.76** (.50)
High drop	**20.85** (.70)	**38.49** (.34)	**34.52** (.23)	**45.67** (.74)
1.14 kg missile				
Low drop	**13.99** (.46)	**17.24** (.06)	**23.23** (.62)	**23.25** (.20)
High drop	**19.86** (.56)	**23.04** (.15)	**29.03** (.44)	**28.90** (.36)
2.30 kg missile				
Low drop	**8.59** (.13)	**9.75** (.19)	**13.13** (.08)	**13.01** (.13)
High drop	**15.16** (.21)	**14.15** (.27)	**18.90** (.69)	**18.93** (.16)

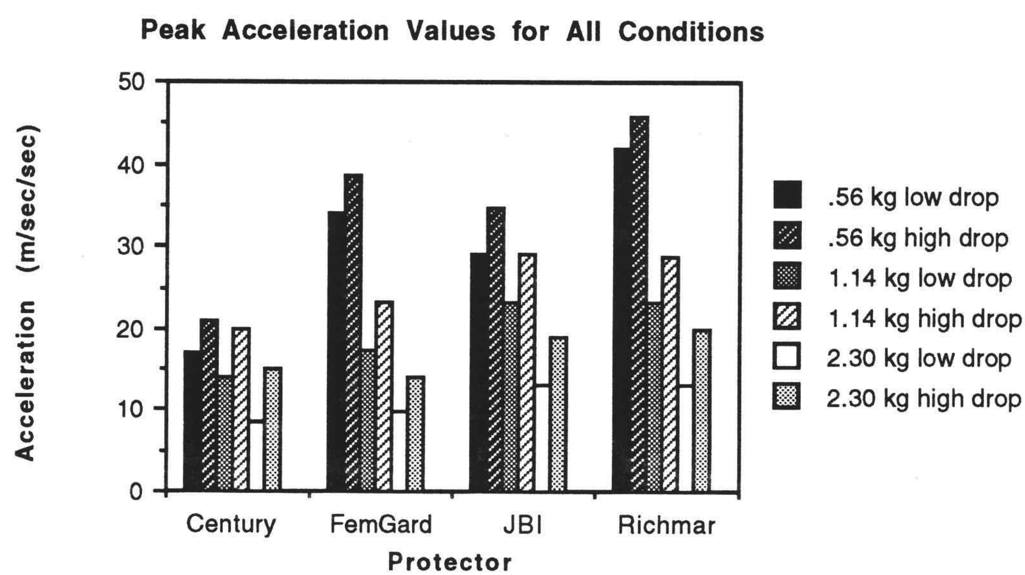


Figure 14. Peak Acceleration Values for All Protectors and Test Conditions

Time-to-Peak-Acceleration. The time that elapses from the initial impact to the instant that maximum acceleration is reached is used as a descriptor of the shock absorbing characteristics of playing surfaces in the ASTM F-355 Test (ASTM, 1990). Longer times-to-peak-acceleration are associated with improved cushioning characteristics. Mean time-to-peak-acceleration data are presented in Table 42 and Figure 15.

Table 42

Time-to-Peak-Acceleration (sec): Means and Standard Deviations (SD)

Protector:	Century	FemGard	JBI	Richmar
Test Condition:				
.56 kg missile				
Low drop	**7.13** (.31)	**9.00** (.35)	**6.47** (.42)	**3.13** (.12)
High drop	**6.60** (.20)	**9.20** (.35)	**6.93** (.12)	**3.40** (.53)
1.14 kg missile				
Low drop	**18.93** (.76)	**14.22** (1.07)	**13.73** (.23)	**8.4** (.35)
High drop	**19.60** (.53)	**15.80** (.20)	**13.73** (.90)	**10.00** (1.91)
2.30 kg missile				
Low drop	**28.13** (1.10)	**19.27** (1.68)	**20.47** (.99)	**15.67** (.95)
High drop	**26.27** (.42)	**21.13** (1.90)	**19.47** (1.16)	**15.93** (.12)

For all test conditions, time-to-peak-acceleration values were shortest for the Richmar protector. For the 1.14 kg and 2.30 kg missile impacts, the foam Century protector produced the longest and most desirable times, while the FemGard showed the longest times for the .56 missile impacts. While short time-to-peak-acceleration values might be undesirable with a point-elastic foam material such as that found in the Century, they are less of a concern for rigid area-elastic armor plates such as those utilized in the Richmar, FemGard and JBI protectors. Even though peak acceleration occurs quickly, the rigid material affords protection by preventing penetration and spreading the impact over a larger surface area, in addition to absorbing energy. These data illustrate the difficulty of trying to attach significance to any obtained values from materials testing with respect to human injury tolerance.

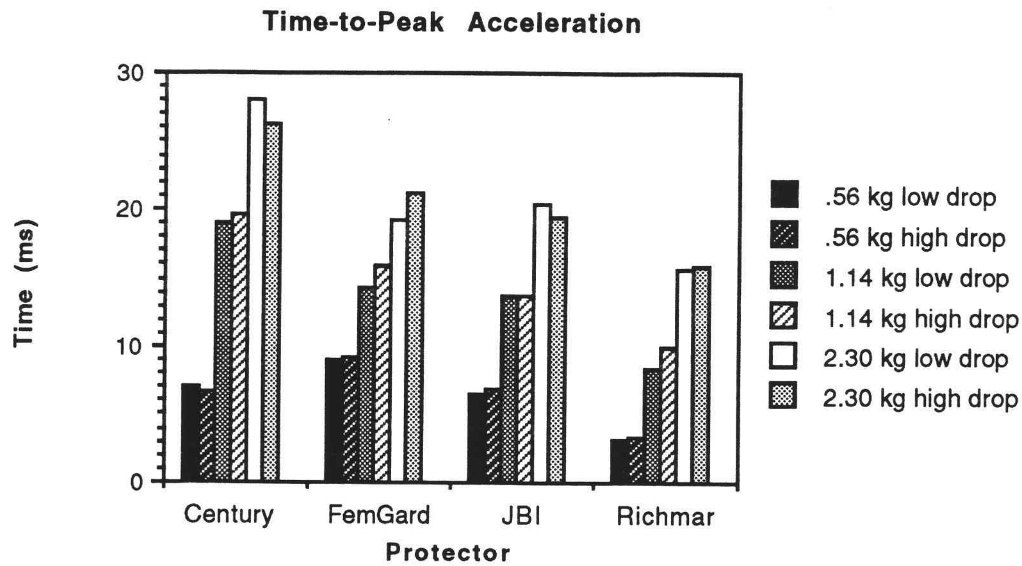


Figure 15. Time-to-Peak-Acceleration Values for All Protectors and Test Conditions

Acceleration-time Histories. Because a great deal of information about material performance can be lost when only isolated peak values are used in evaluation (Nigg, 1990), examination of acceleration data across the time history of the impact are used in this study to provide additional insight into the cushioning characteristics of the protectors tested. In the following acceleration-time histories, the records from all three drops for each experimental condition are superimposed on each other to indicate the variability of the observed phenomenon.

Century protector. The acceleration-time histories generated from the Century protector by the .56 kg missile are illustrated in Figure 16. The duration of the impact for both low and high drop height conditions was approximately 27 milliseconds (ms). The geometries of the curves from the high and low drops are similar, with a double-peaked, somewhat symmetrical domed shape. This "saddle," which appears after peak acceleration, occurs only in the curves generated by the lightest (.56 kg) missile.

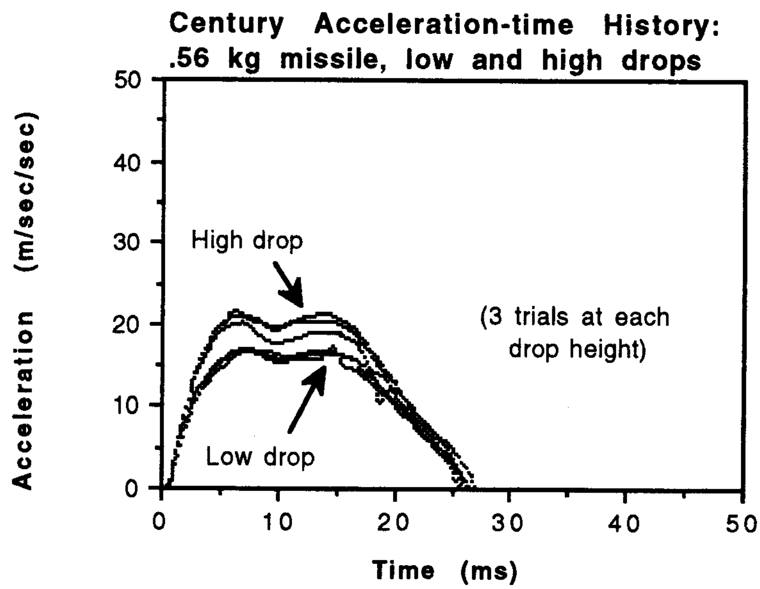


Figure 16. Century Acceleration-time History: .56 kg missile

The acceleration-time histories for the high and low drops of the 1.14 kg missile (Figure 17) can be described as broad, somewhat asymmetrical rounded peaks with durations nearly double those of the .56 missile drops. Both curves exhibit a steeper rise in the first 2-3 ms, followed by a decrease in slope up to the peak value, which occurs around 20 ms. The asymmetry of the curves may be related to hysteresis effects that are common with foam materials.

Acceleration-time histories for the 2.30 kg missile for both low and high drops (Figure 18) are quite similar to those observed for the 1.14 kg test conditions. The impact event is spread over an even longer period of time than was seen for the .56 kg and 1.14 kg missiles, approaching 60 ms for the low drop.

The Century protector appears to attenuate the administered shock in a relatively gradual manner under all test conditions employed in this study, reducing peak acceleration values and spreading the impact event over a longer period of time as compared to the other protector styles (Figures 14 and 15). These results are consistent with the known shock-attenuating behavior of closed-cell foams.

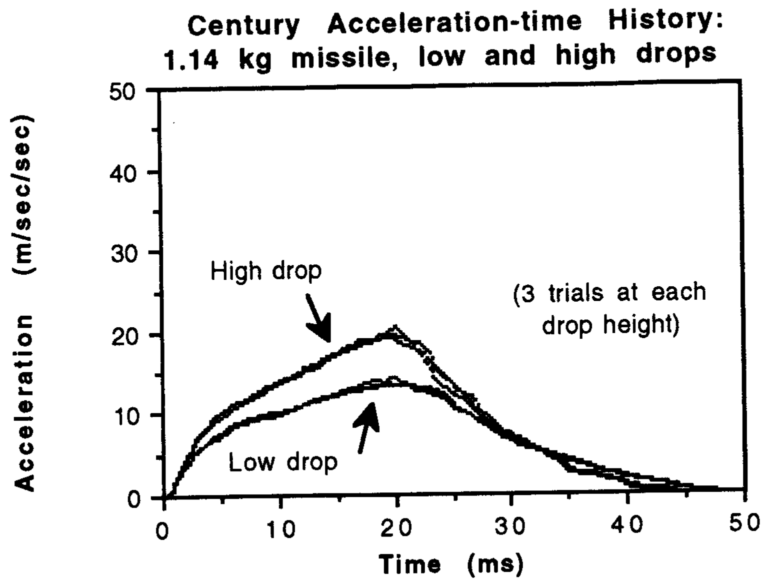


Figure 17. Century Acceleration-time History: 1.14 kg missile

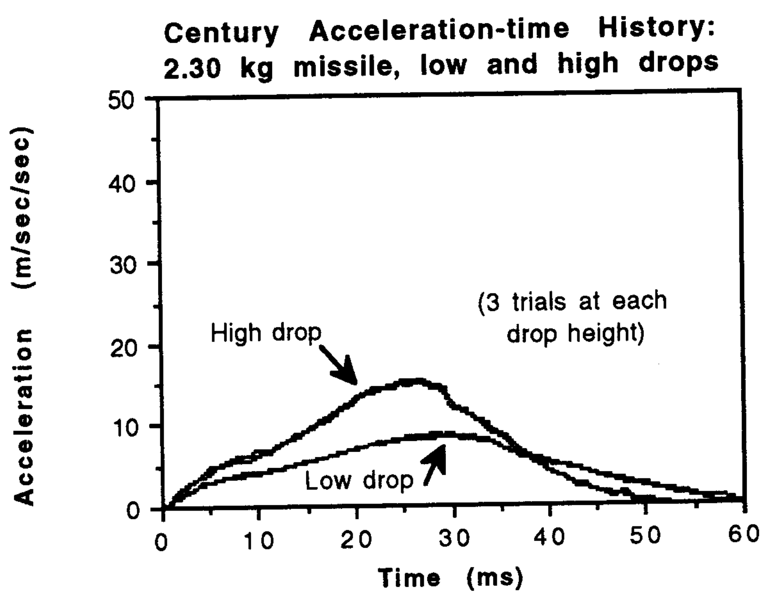


Figure 18. Century Acceleration-time History: 2.30 kg missile

FemGard protector. The acceleration-time curves for the low and high drops of the .56 kg missile on the FemGard protector are illustrated in Figure 19. These curves are higher and steeper than those observed with the .56 kg missile for the Century protector. Both curves generally exhibit a steep rise in acceleration followed by a brief dip and subsequent rise to peak acceleration. After the peak, values fall off rapidly, with the entire impact event occuring in 20-23 ms. The dip observed at the tops of the curves is a somewhat curious effect. The fact that it did not occur in one of the low drop trials suggests that the phenomenon could be related to the interaction between the geometries of the protector and the .56 kg projectile.

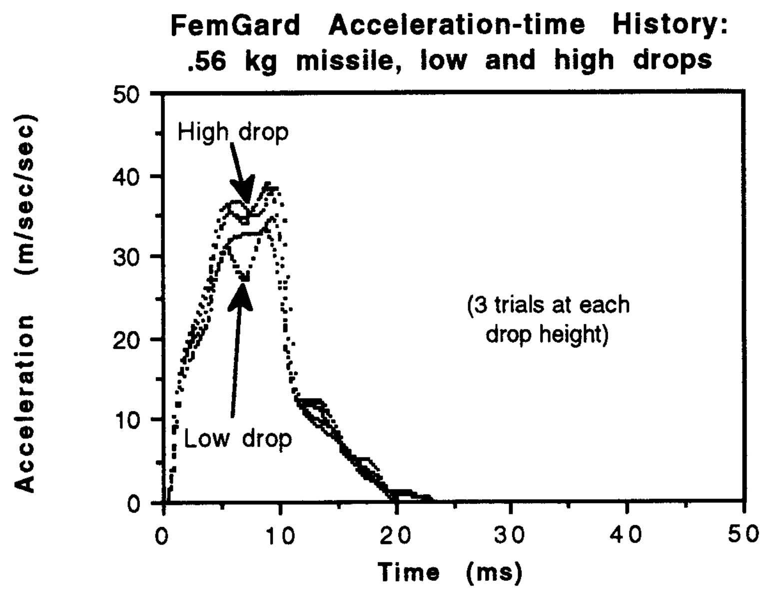


Figure 19. FemGard Acceleration-time History: .56 kg missile

The acceleration-time curve for the 1.14 kg missile (Figure 20) low drop is somewhat rounded but distinctly asymmetrical. Initially the curve is characterized by a steep rise, followed by a distinct flattening of the slope at about 2-3 ms which forms a "knee" in the curve. Acceleration then rises more slowly with some slight oscillation up to the peak value at about 16 ms, then falls to zero by approximately 30 ms.

The curve for the high drop of the 1.14 kg missile follows a higher but similar course, with the exception that the top of the curve exhibits distinct three peaks occurring at approximately 3 ms intervals. As will subsequently be seen, these apparent oscillations in acceleration are present in all 1.14 kg drops for the three rigid plastic protectors (FemGard, JBI, Richmar), and are particularly prominent in the 2.30 kg high drops for these protectors. The surface and mass impacted by the missiles in this study included several heterogenous elements with unique mechanical characteristics: the protector itself; the prosthetic breast; the foam and fiberglass torso anvil beneath the protector and breast, and the wood and metal structure supporting the protector and missile track. Complex interactions among these elements of varying elastic properties and asynchrony in their responses to the more severe applied impacts may offer some explanation for the oscillations observed in the acceleration-time curves of the rigid protectors. In addition, the crystal in the accelerometer possesses a natural frequency that can produce resonance under certain impact conditions. However, this natural frequency is much higher than that of the oscillations observed here.

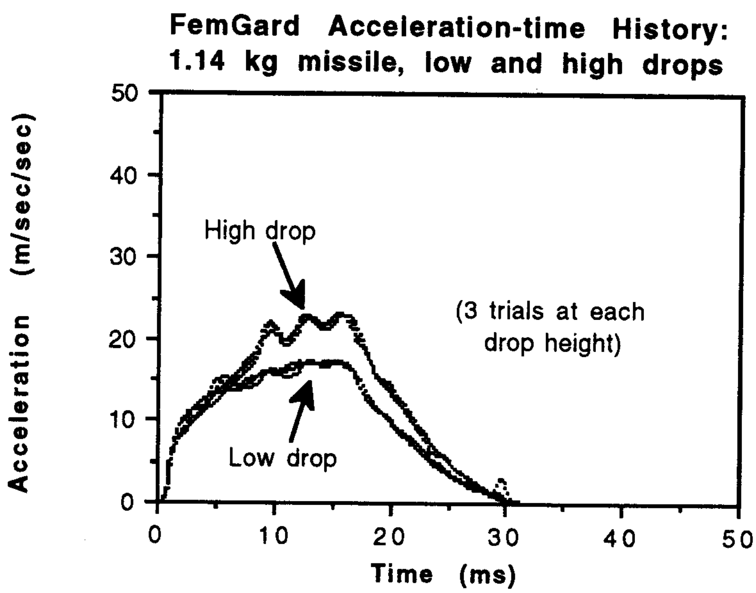


Figure 20. FemGard Acceleration-time History: 1.14 kg missile

The acceleration-time curves for the 2.30 kg high and low drops (Figure 21) on the FemGard protector demonstrate fairly symmetrical curves of similar geometry, with the high drop generating somewhat higher acceleration values. The 2.30 kg curves are of approximately 10-12 ms greater duration than the 1.14 kg curves of the FemGard. The oscillation effect discussed above is particularly apparent in the high drop.

When compared to the Century protector, the FemGard appears to attenuate the shock of the administered impacts to a lesser degree and in a somewhat more abrupt manner, as peak acceleration values are higher and the return of acceleration values to zero occurs over a relatively shorter period of time. These results are consistent with the stiff, area elastic properties of the polyethylene material from which the FemGard protector is constructed.

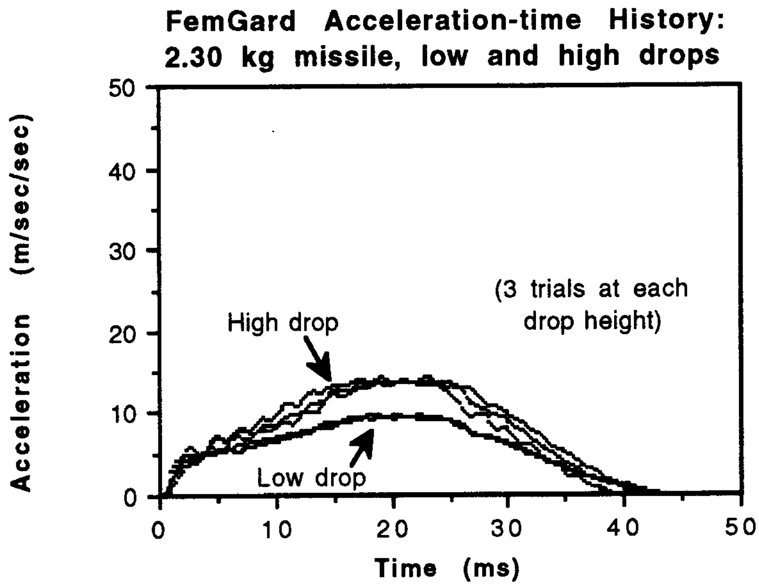


Figure 21. FemGard Acceleration-time History: 2.30 kg missile

JBI protector. The acceleration-time curves of the .56 kg low and high drops on the JBI protector (Figure 22) are similar to those of the FemGard in that both the rise and fall of the curves are characterized by the relatively steep slopes common to stiff materials. The JBI curves, however, do not exhibit the same dips at the top of the curves prior to peak acceleration as can be seen in the FemGard curves but instead are somewhat smooth at the crown.

The acceleration-time curves for the 1.14 kg drops on the JBI protector (Figure 23) show great similarities to those of the FemGard protector, including the oscillations along the crown of the high drop curve. The JBI's peak acceleration values are moderately higher than those of the FemGard, resulting in a higher curve. The low drop curve for the JBI, however, shows a rather curious spike of unknown etiology at about 13 ms in all three trials that is not present in the FemGard data. As previously discussed, the complex interactions among the heterogenous elements in the protectors and test equipment may produce patterns in the acceleration-time curves which are not readily explained given the simplicity of the test method.

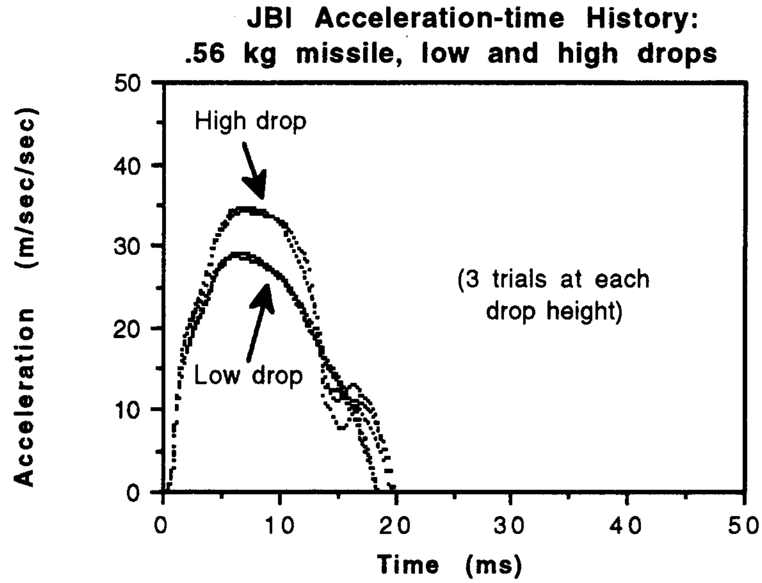


Figure 22. JBI Acceleration-time History: .56 kg missile

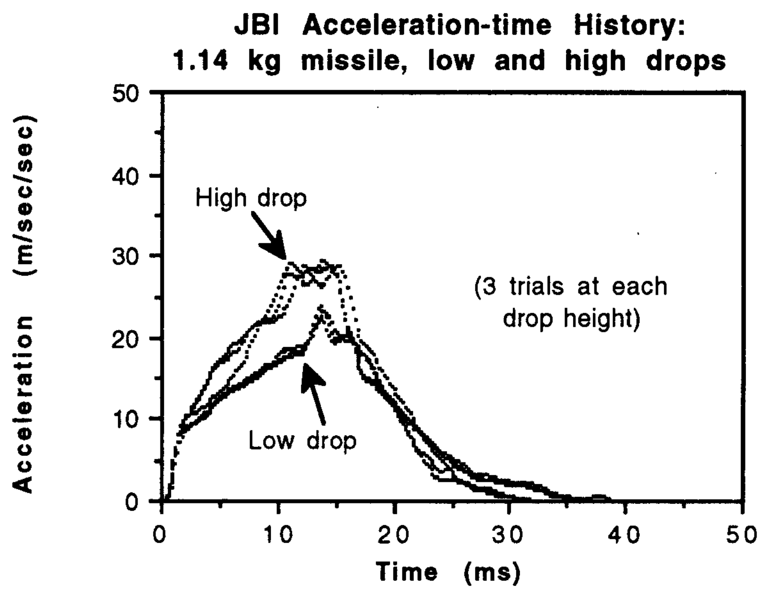


Figure 23. JBI Acceleration-time History: 1.14 kg missile

The acceleration-time curves for the high and low drops of the 2.30 kg missile on the JBI protector (Figure 24) closely resemble those of the FemGard protector, with the exception that acceleration values for both high and low drops are generally higher. The curves include the distinct oscillations throughout the curve, particularly in the case of the high drop curve. The duration of the impact event, about 40 ms, is similar to that of the FemGard protector, and approximately two-thirds the duration of 60 ms observed for the foam Century protector.

Overall, the response of the JBI protector to the range of applied impacts was similar to that of the FemGard protector, in that peak acceleration values were higher and occurred more quickly when compared to the Century protector data. Again, these results would be expected from the stiff, area elastic materials such as those found in the JBI and FemGard protectors.

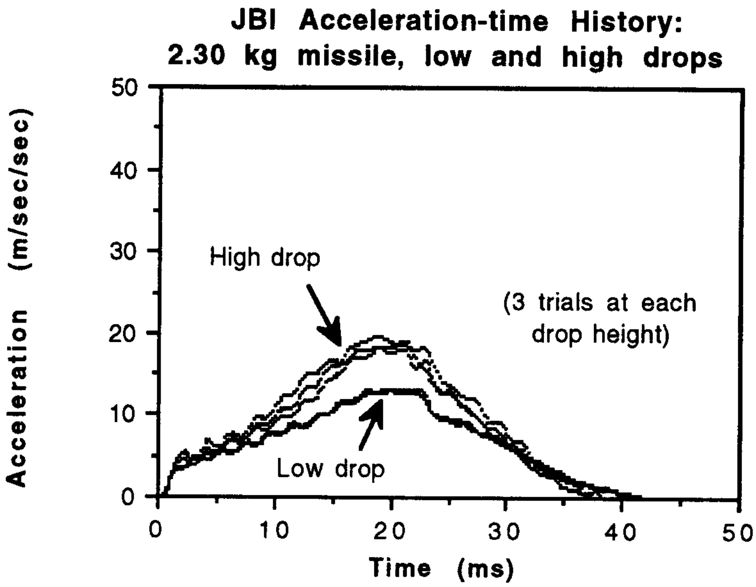


Figure 24. JBI Acceleration-time History: 2.30 kg missile

Richmar protector. The acceleration-time curves for the .56 kg high and low drops on the Richmar protector (Figure 25) exhibit extremely steep rises to peak acceleration as compared to all other protectors, with a return to zero within only about 15 ms. This pattern is typical of the response expected from a very rigid material such as that found in the Richmar.

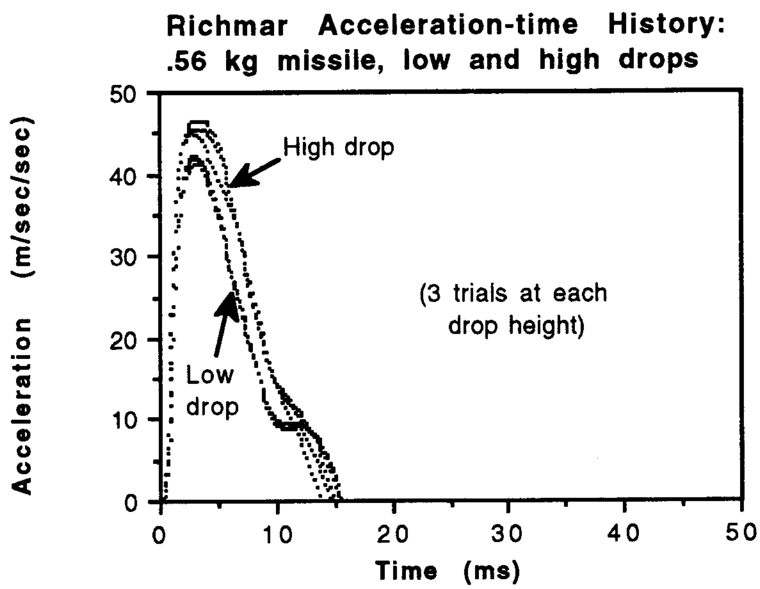


Figure 25. Richmar Acceleration-time History: .56 kg missile

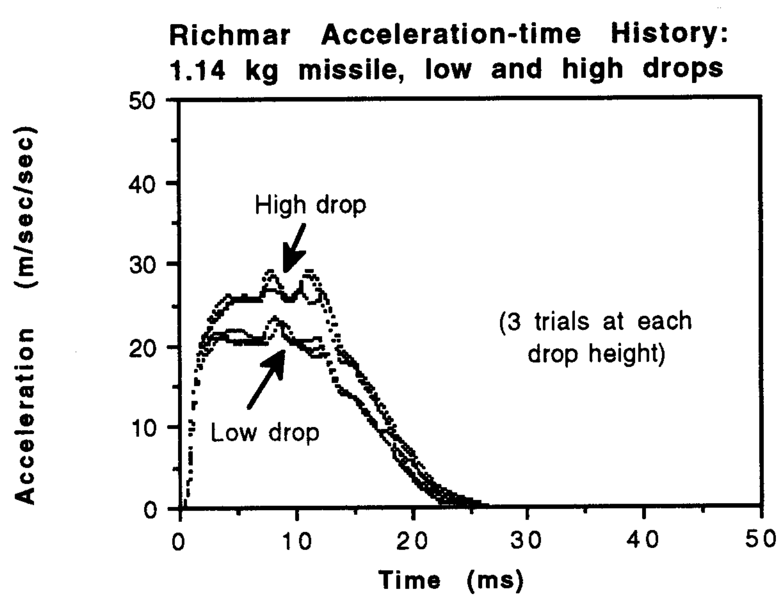


Figure 26. Richmar Acceleration-time History: 1.14 kg missile

The acceleration-time curves for the high and low drops of the 1.14 kg missile on the Richmar protector (Figure 26) exhibit several of the same characteristics of those of the FemGard and JBI protectors. Whereas the initial rise in acceleration is much steeper than that seen with the other two protectors, the oscillations along the crown of the curve are similar, and the duration of the impact event is only slightly shorter.

The Richmar protector's acceleration-time curves for the low and high drops of the 2.30 kg missile demonstrate the most pronounced oscillation effect of all test conditions (Figure 27). The first waves appear at about 2 ms and persist strongly through the rise of the curve. They gradually attenuate as acceleration values fall to zero. The duration of the impact event for the 2.30 kg missile is moderately shorter than that observed for the FemGard and JBI protectors, and markedly shorter than that of the Century protector.

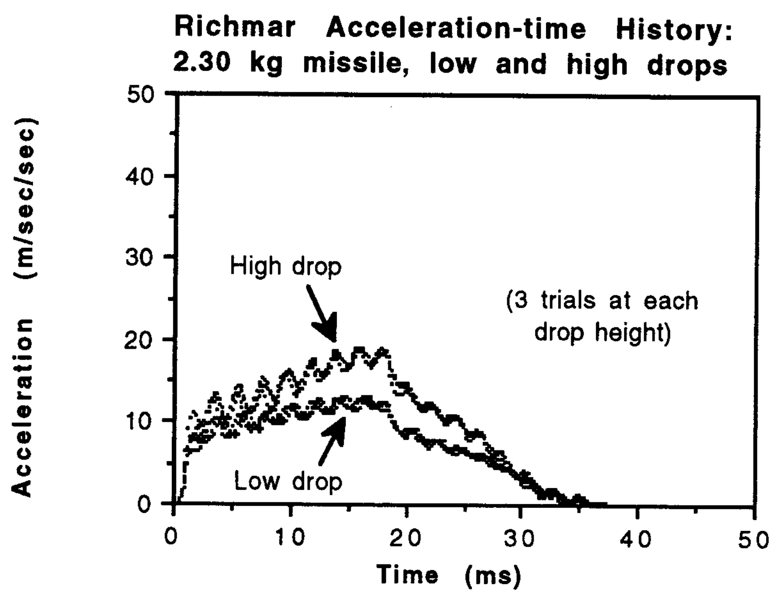


Figure 27. Richmar Acceleration-time History: 2.30 kg missile

The relatively high peak acceleration and short time-to-peak-acceleration values associated with the Richmar, FemGard, and JBI protectors for the majority of test conditions suggest that the high density polyethylene materials of which they are constructed do not attenuate shock to the degree that a softer material such as a closed-cell foam found in the Century does. However, since the rigid protectors are functionally designed more to prevent impacting objects from reaching biological tissues rather than to simply attenuate shock, this finding does not imply that the rigid protectors tested in this study afford less protection than the foam Century protector against potential injury to biological tissues.

Energy Absorption

Peak Displacement Values. Two integrations were performed on acceleration data to yield displacement values for the creation of force-displacement curves. Peak displacement data are displayed in Table 43 and Figure 28.

Table 43

Peak Displacement Values (mm): Means and Standard Deviations (SD)

Protector:	Century	FemGard	JBI	Richmar
Test Condition:				
.56 kg missile				
Low drop	**27.02** (.83)	**16.47** (.77)	**17.23** (.19)	**12.15** (.37)
High drop	**31.22** (1.13)	**20.00** (.33)	**20.79** (.25)	**14.50** (.11)
1.14 kg missile				
Low drop	**32.61** (.25)	**22.67** (.30)	**23.38** (.26)	**16.14** (.33)
High drop	**50.15** (.33)	**39.68** (.46)	**35.76** (1.20)	**27.21** (.02)
2.30 kg missile				
Low drop	**35.81** (.09)	**25.82** (.23)	**25.59** (.08)	**18.33** (.06)
High drop	**45.30** (.77)	**37.44** (1.39)	**36.31** (1.53)	**26.88** (.85)

Inspecting the peak values yields some insight into the mechanisms of protection of the various protectors. Displacement values for all drop testing conditions tended to be highest for the Century protector. Whereas the other styles utilize rigid plates as their protective mechanism, the Century is constructed of compressible closed-cell foam which converts the kinetic energy of the impact into potential and heat energy. Because this material can deform relatively easily, displacement is facilitated. Also, because the Century is not rigid, it is possible that the impact was able to reach the underlying soft prosthetic breast, which could also deform beneath the protector in response to the impact of the projectile allowing further displacement of the Century.

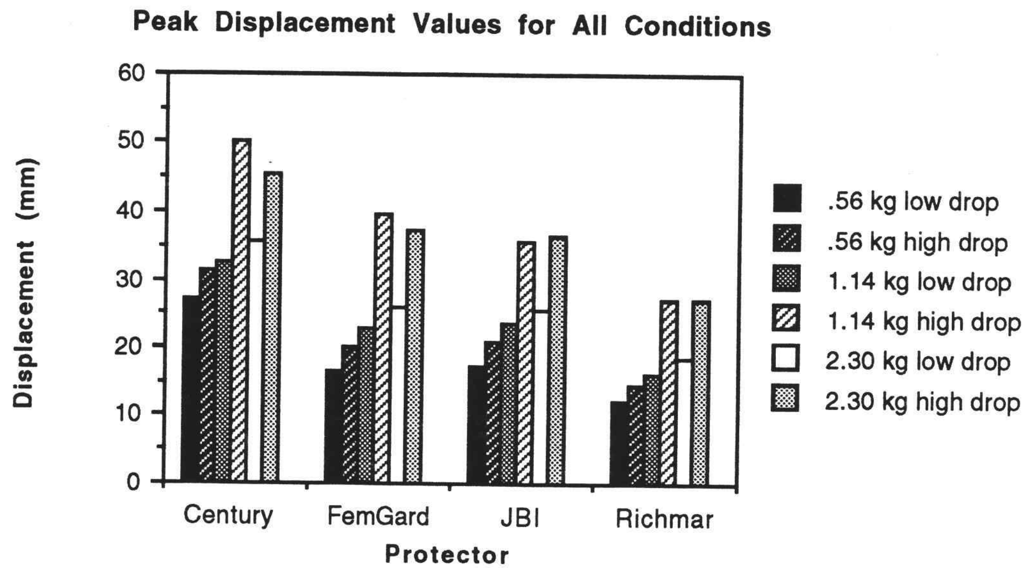


Figure 28. Peak Displacement Values for All Protectors and Test Conditions

Peak displacement values for the Richmar were generally the smallest of all protectors. This protector is one solid piece of rigid plastic resting on two relatively rigid aspects of the chest, the sternum and the ribs (in this study, the fiberglass-reinforced torso), and bridging over the soft tissue of the breast. Unless the applied forces were great enough to compress the rigid torso, displacement of this protector would be somewhat limited.

Peak displacement values tended to be intermediate for the JBI and FemGard protectors. These two protectors are generally composed of two smaller, separate pieces of plastic resting primarily over soft breast tissue rather than the ribs. Whereas they could not easily deform in response to an impact as the closed-cell material of the Century could, because of their size and position they may have been less stable and more free to shift in a lateral direction under load than the Richmar protector.

Peak Force Values. The peak contact force between the dropping mass and the chest/breast protector was calculated from the maximum acceleration in the time-acceleration history for each missile and drop height using the relationship Force(t) = mass * acceleration(t). Peak values for all test conditions are presented in Table 44 and graphically displayed in Figure 29.

Table 44

Peak Force Values (N): Means and Standard Deviations (SD)

Protector:	Century	FemGard	JBI	Richmar
Test Condition:				
.56 kg missile				
Low drop	**9.45** (.10)	**18.94** (.32)	**16.21** (.14)	**23.34** (.28)
High drop	**11.65** (.39)	**21.51** (.19)	**19.30** (.13)	**25.53** (.41)
1.14 kg missile				
Low drop	**15.89** (.52)	**19.57** (.07)	**26.37** (.70)	**26.40** (.23)
High drop	**23.95** (2.21)	**26.16** (.18)	**32.95** (.50)	**32.80** (.41)
2.30 kg missile				
Low drop	**17.79** (.30)	**22.46** (.43)	**30.24** (.17)	**29.97** (.30)
High drop	**34.92** (.47)	**32.60** (1.39)	**43.54** (1.59)	**43.60** (.37)

Inspection of the bar chart of peak values indicates that the peak values associated with impacts to the Century protector were generally less than those of the other protectors while those for the Richmar were generally greater. Values for the FemGard and JBI protectors tended to be intermediate to the Century and Richmar. However, there were exceptions to those trends as the JBI's values were similar to those of the Richmar for the 1.14 and 2.30 kg missiles.

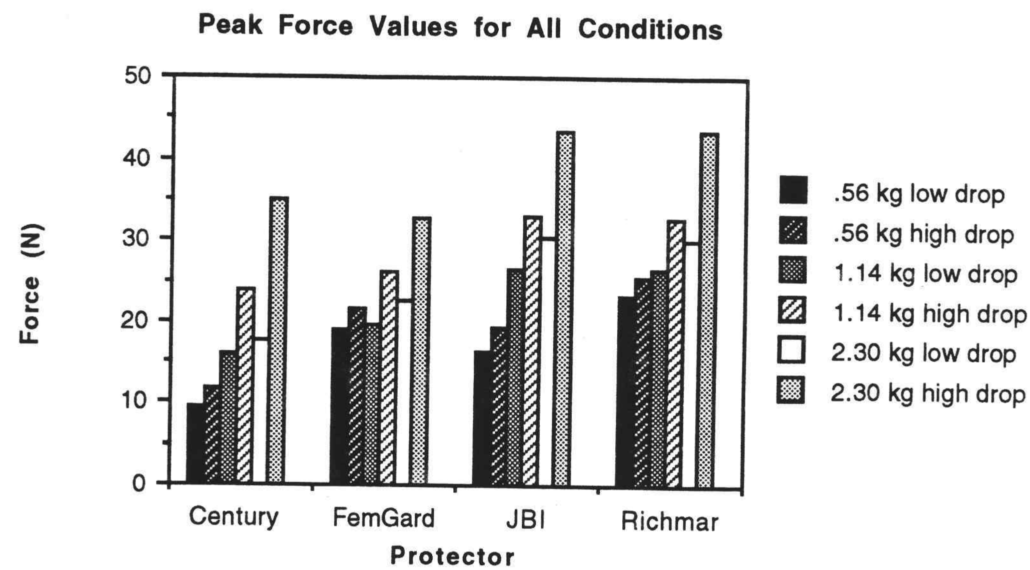


Figure 29. Peak Force Values for All Protectors and Test Conditions

Force-Displacement Curves: Stiffness and Shock Absorption Characteristics

Force-displacement curves provide a means of assessing both the stiffness and energy absorption characteristics of cushioning materials. The curves consist of an upper curve representing the loading phase of the force application, and a lower curve curve detailing the unloading or recovery phase. The slope of the loading phase, that is, the amount of displacement associated with a given force application, is indicative of the stiffness of the material. An estimate of the shock absorption characteristics of a material may be derived by numerically integrating under the curves of both the loading and unloading phases, and by calculating the difference in area between the two curves by subtracting the area under the unloading curve from that under the loading curve. In the final two sections of this chapter, force-displacement curves for all test conditions are presented to enable the qualitative discussion of stiffness characteristics, followed by the quantitative comparison of shock absorption characteristics. The curves for the three trials performed for each experimental condition are superimposed on each other to illustrate their variability.

Century protector. The force-displacement curves for all missile drops on the Century protector are characterized by a gradual rise rather than a steep slope during the loading phase (Figures 30, 31 and 32). A slight "knee" is present at about 17 and 25 mm of displacement, respectively, in the 2.30 kg low and high drops (Figure 32), with an apparent steepening in slope at this point that suggests a change in stiffness. These patterns are typical of closed-cell foam materials. Under impact, the compression of the gases in the closed cells provide the first and best mechanism for gradually absorbing the kinetic energy of the impact. After the gases are fully compressed and the cells become relatively flattened, the material tends to stiffen. While some additional energy is absorbed as the material itself is compressed, displacement of the flattened material toward the body may result in the unwanted effect of some kinetic energy being transmitted to biological tissues (Watkins, 1984).

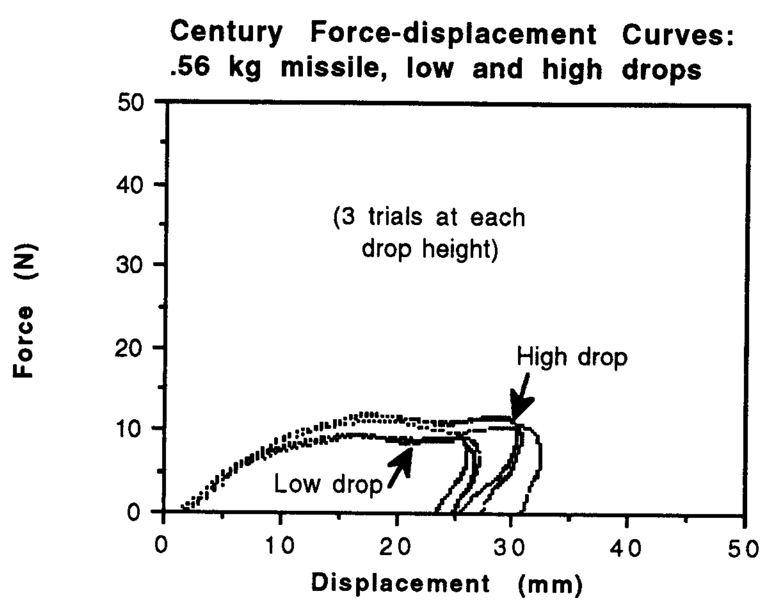


Figure 30. Century Force-displacement Curves: .56 kg Missile

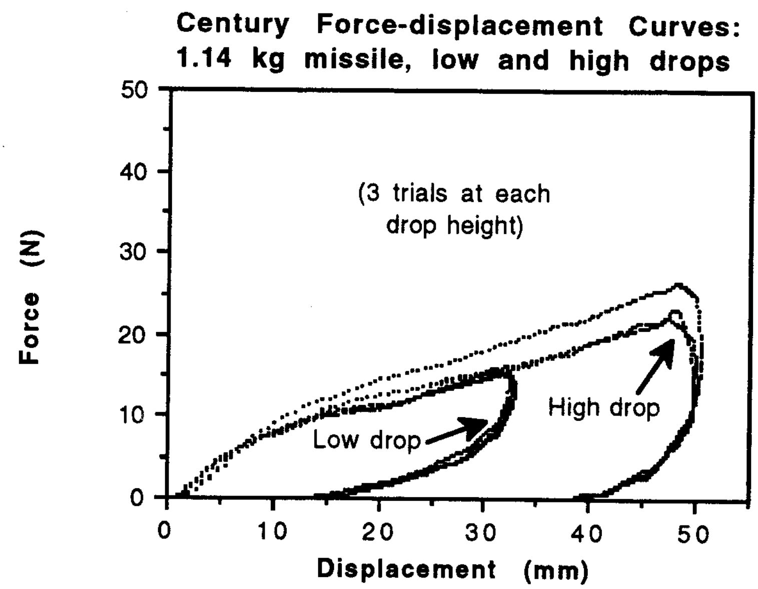


Figure 31. Century Force-displacement Curves: 1.14 kg Missile

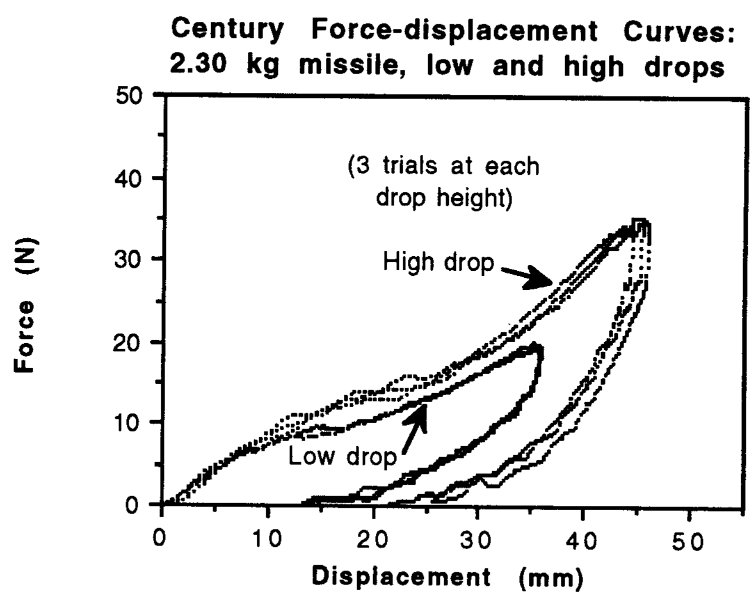


Figure 32: Century Force-displacement Curves: 2.30 kg Missile

FemGard protector. The slope of the loading phase of the force-displacement curves of the low and high drops of the .56 kg missile on the FemGard (Figure 33) are noticably steeper than those of the Century (Figure 30), suggesting a stiffer response to the impact. For the 1.14 and 2.30 kg drops, however, whereas the loading curves for the FemGard

(Figures 34 and 35) are much steeper in the initial stages of displacement, the slopes flatten rather abruptly and then parallel those of the Century (Figures 31 and 32) for the remainder of the loading curve.

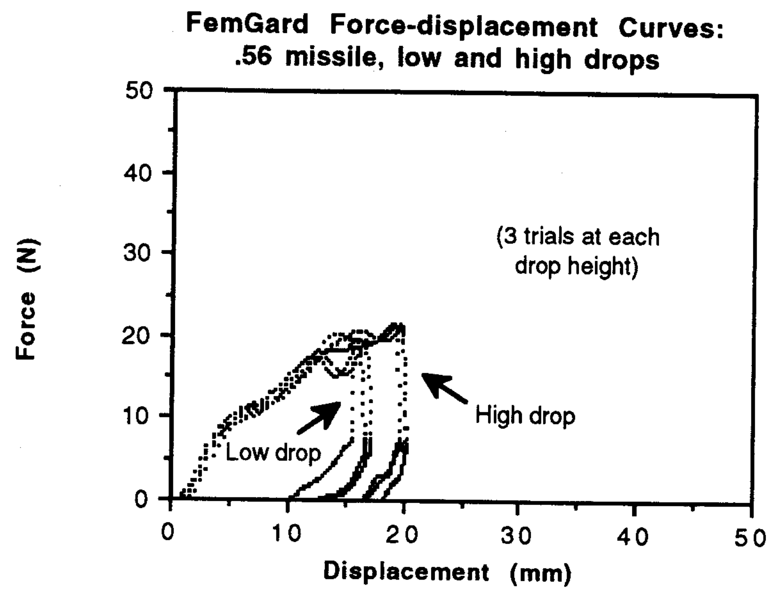


Figure 33. FemGard Force-displacement Curves: .56 kg Missile

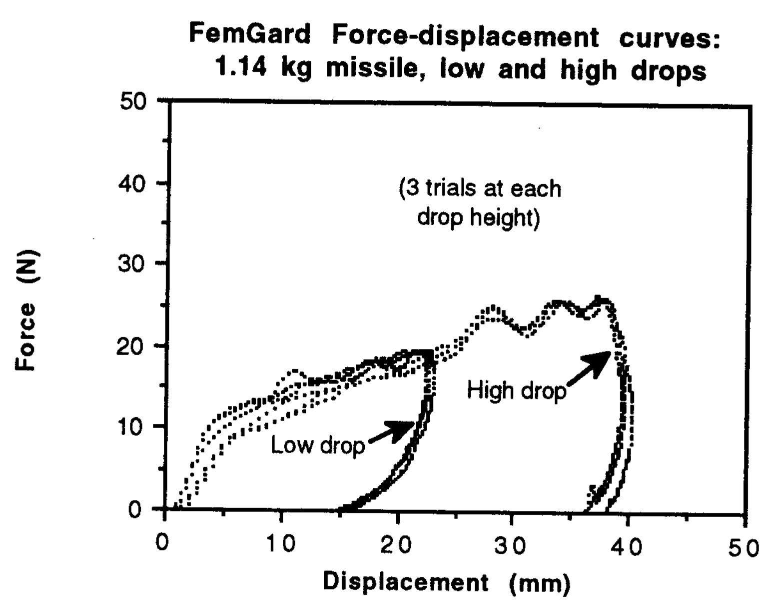


Figure 34. FemGard Force-displacement Curves: 1.14 kg Missile

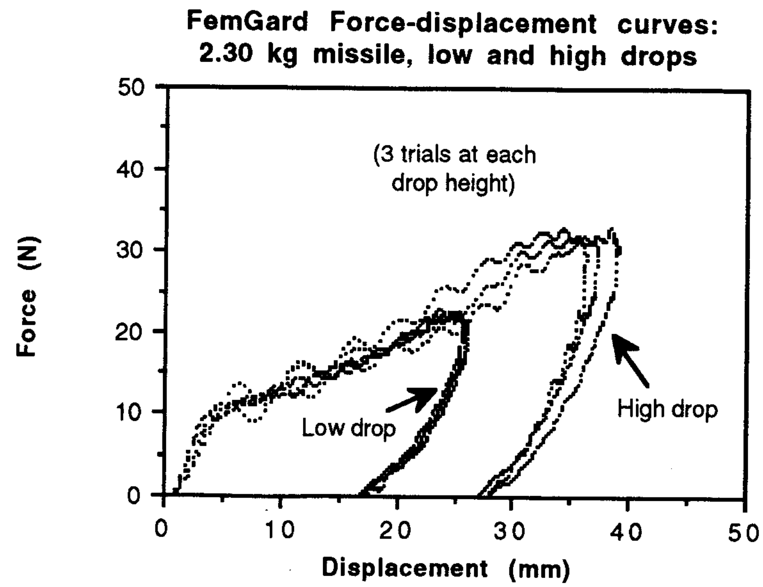


Figure 35. FemGard Force-displacement Curves: 2.30 kg Missile

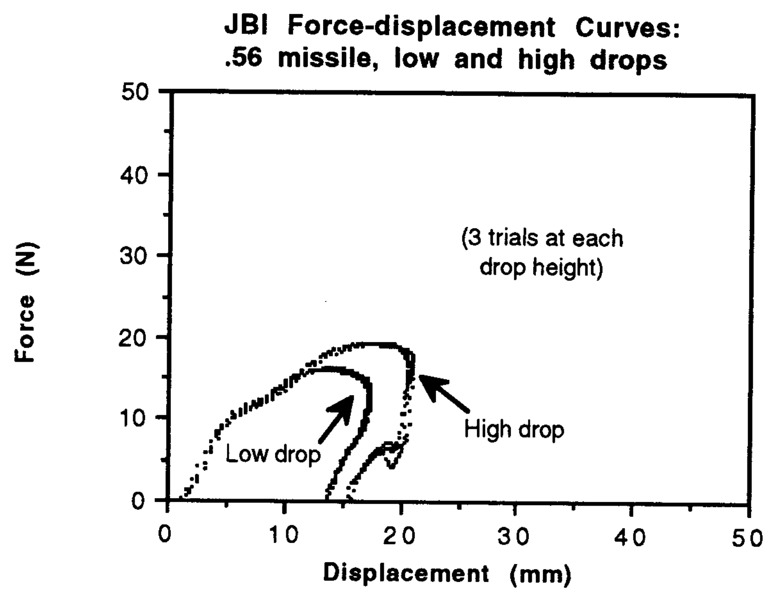


Figure 36. JBI Force-displacment Curves: .56 kg Missile

<u>JBI protector</u>. The slopes of the JBI protector's loading curves for the .56 kg and 1.14 kg missiles (Figures 36 and 37) closely resemble those of the FemGard, indicating similar stiffness characteristics. The JBI's

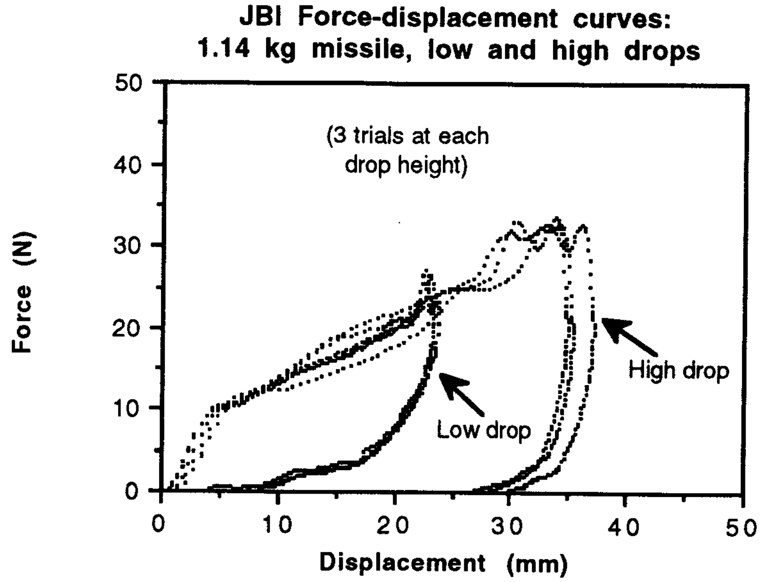


Figure 37. JBI Force-displacement Curves: 1.14 kg Missile

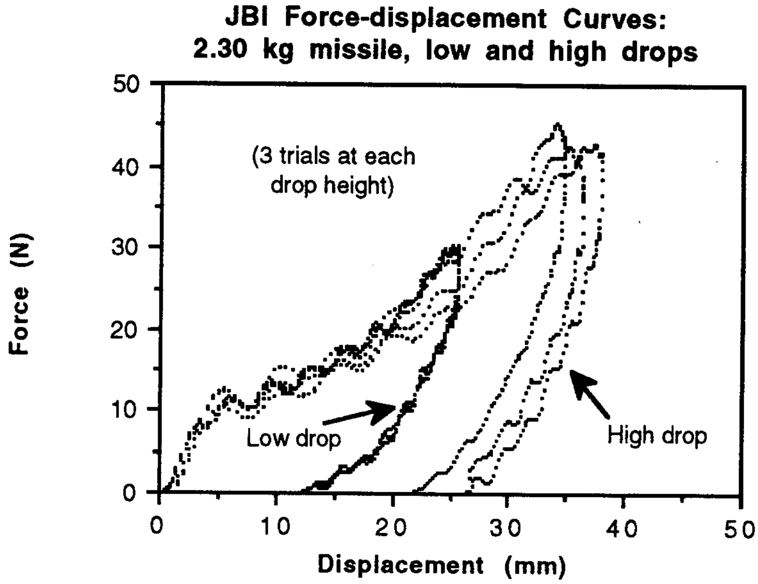


Figure 38: JBI Force-displacement Curves: 2.30 kg Missile

loading curve for the 2.30 kg missile (Figure 38), however, deviates sharply upward from the pattern seen for both the Century (Figure 32) and FemGard (Figure 35) protectors midway up the rise. This suggests a further stiffening in the response of the JBI to the 2.30 kg missile at this point as compared to the FemGard and Century protectors.

Richmar protector. The slopes of the loading curves for the high and low drops of the .56 kg missile on the Richmar protector (Figure 39) are moderately more steep than those observed for the FemGard and JBI, and markedly more so than those of the Century, suggesting that this protector possesses the stiffest characteristics for these test conditions. The 1.14 and 2.30 kg test conditions produced loading slopes that are distinctly steeper for the Richmar (Figures 40 and 41) than for all other protectors, particularly in the first half of the rise of the curve. As discussed previously, the fact that the Richmar is constructed of one rather large, solid piece of plastic and rests on two relatively rigid aspects of the chest enhances its ability to resist displacement under high force conditions as compared to protectors of less rigid design and construction.

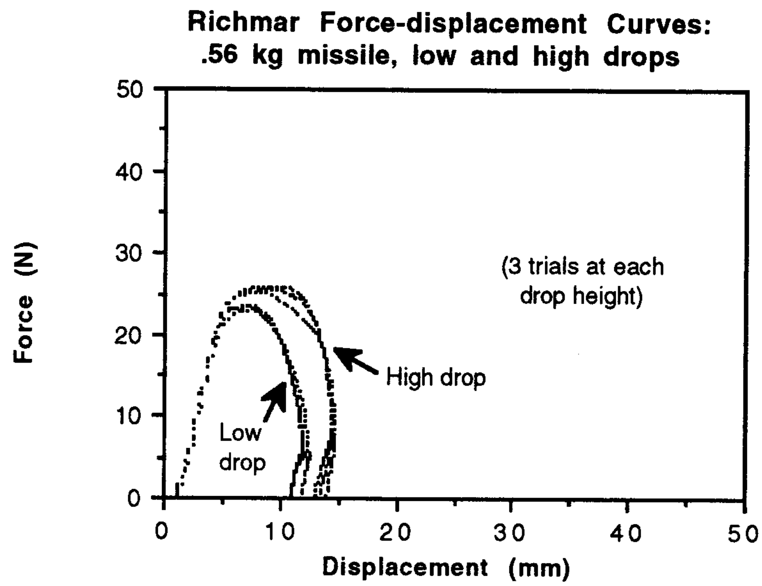


Figure 39. Richmar Force-displacement Curves: .56 kg Missile

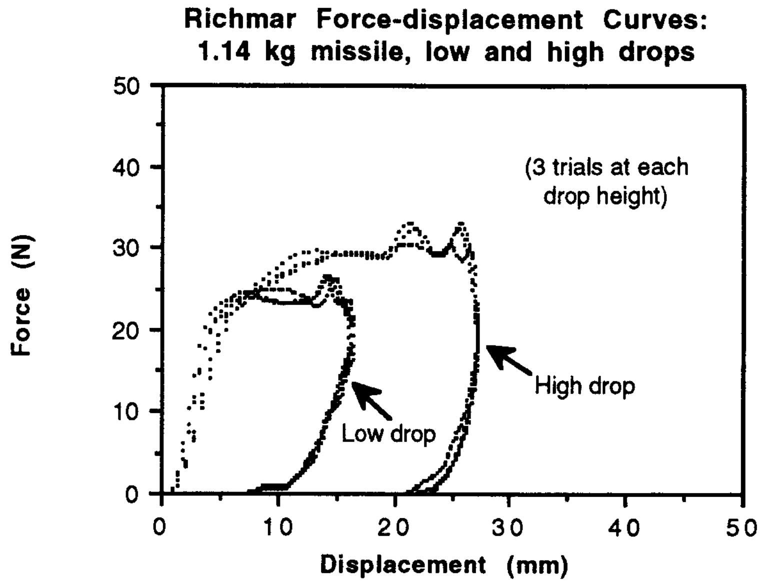


Figure 40. Richmar Force-displacement Curves: 1.14 kg Missile

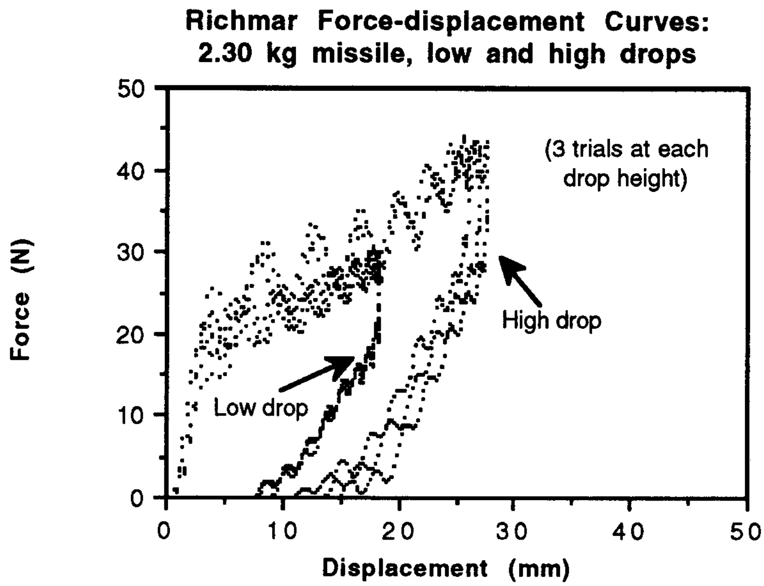


Figure 41. Richmar Force-displacement Curves: 2.30 kg Missile

Overall, the general pattern that emerged from the slopes of the force-displacement curves for all test conditions suggests that the Richmar protector possessed the stiffest material characteristics of the four protectors tested. The Century was identified by its loading curves as the softest material, while the FemGard and JBI results showed stiffness characteristics intermediate to the Richmar and Century. These findings are consistent with the design, materials and size of the individual protectors.

Percent of Energy Absorbed

Energy absorption characteristics of protective materials can be especially important in sports where another player's body part, such as an elbow or head, is responsible for delivering the blow. Energy that is returned to the impacting body part rather than absorbed by the protector can constitute a potential source of injury. Hence, more desirable protective padding systems would generally be characterized by greater energy absorption properties. Estimates of the shock absorption characteristics of each protector were derived by numerically integrating under the force-displacement curves of both the loading and unloading phases, and by calculating the difference in area between the two curves by subtracting the area under the unloading curve from that under the loading curve. The value thus derived, which represents the energy absorbed, was then expressed as a percentage of the the energy applied during the loading phase. Results and discussion of mean energy absorption percentage values and the analysis of variance procedures performed on shock absorbency data for each combination of missile size and drop height are presented below.

Energy Absorption Results. Mean energy absorption percentage data for the six different sets of test conditions are presented in Table 45 and Figure 42. Generally, energy absorption values tended to decrease with increasing missile mass for a given drop height, but values for the FemGard and JBI 1.14 kg high drops are notable exceptions to this trend. These data confirm Nigg's (1990) contention that changing missile mass, drop height, or surface contact area can rearrange the rank order of results for various surfaces.

Table 45

Energy Absorption (%): Means and Standard Deviations (SD)

Protector:	Century	FemGard	JBI	Richmar
Test Condition:				
.56 kg missile				
Low drop	**96.53** (.93)	**94.00** (3.44)	**89.15** (.73)	**98.23** (.43)
High drop	**95.34** (2.39)	**96.77** (1.17)	**88.94** (1.15)	**98.46** (.79)
1.14 kg missile				
Low drop	**78.80** (1.37)	**89.45** (.13)	**76.37** (.70)	**96.91** (.32)
High drop	**93.99** (.29)	**98.24** (.52)	**95.47** (.16)	**96.14** (.96)
2.30 kg missile				
Low drop	**67.95** (.93)	**83.14** (.79)	**72.84** (.58)	**76.32** (.75)
High drop	**73.01** (.47)	**86.00** (2.21)	**81.04** (2.02)	**78.23** (1.77)

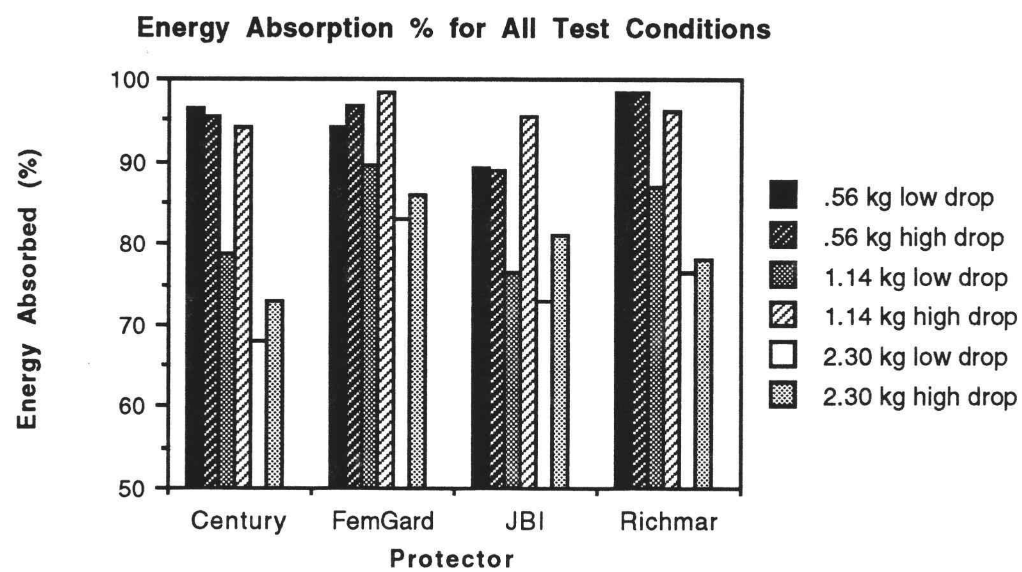


Figure 42. Percent of Applied Energy Absorbed for All Test Conditions

Significant differences in the percentage of energy absorbed during the .56 kg low drop were found among the four protectors, $F(3, 6) = 17.15$, $p < .0024$, as shown in Table 46. Analysis of pairwise differences (Table 47) indicated that the Century and Richmar protectors absorbed a significantly greater percentage of the applied energy than the JBI protector.

Table 46

ANOVA Repeated Measures Summary Results: Percent of Energy Absorbed, .56 kg Missile, Low Drop Height

Source	df	SS	MS	F	p level
Treatments	3	141.807	47.269	17.15	.0024
Blocks	2	10.329	5.165		
Error	6	16.540	2.757		
Total	11	168.677			

Table 47

Analysis of Pairwise Differences (Scheffé): Percent of Energy Absorbed, .56 kg Missile, Low Drop Height

Style	JBI	FemGard	Century	Richmar
Mean (S.D.)	89.15 (.73)	94.00 (3.44)	96.53(.93)	98.23 (.43)

Note. Means underscored by the same line not significantly different at $p < .05$.

At the high drop height for the .56 kg missile, significant differences in energy absorption were again observed, $F(3, 6) = 51.91$, $p < .0001$ (Table 48). The Century, FemGard and Richmar protectors' energy absorption percentages were significantly greater than that of the JBI (Table 49). In addition, the Richmar's percentage was greater than that of the Century.

Table 48

ANOVA Repeated Measures Summary Results: Percent of Energy Absorbed, .56 kg Missile, High Drop Height

Source	df	SS	MS	F	p level
Treatments	3	155.380	51.793	51.91	.0001
Blocks	2	12.081	6.040		
Error	6	5.987	.998		
Total	11	173.447			

Table 49

Analysis of Pairwise Differences (Scheffé): Percent of Energy Absorbed, .56 kg Missile, High Drop Height

Style	JBI	Century	FemGard	Richmar
Mean (S.D.)	88.94 (1.15)	95.34 (2.39)	96.77 (1.17)	98.46 (.79)

Note. Means underscored by the same line not significantly different at $p < .05$.

Significant differences in the percentage of energy absorbed during the 1.14 kg low drop were found among the four protectors, $F(3, 6) = 162.31$, $p < .0001$, as shown in Table 50. Analysis of pairwise differences (Table 51) indicated that the FemGard and Richmar protectors absorbed a significantly greater percentage of the applied energy than the JBI and Century protector.

At the high drop height, the 1.14 kg missile also generated significant differences in energy absorption among the four protectors, $F(3, 6) = 27.09$, $p < .0007$, as indicated in Table 52. Examination of pairwise comparisons (Table 53) revealed that the FemGard absorbed significantly more energy under these test conditions than the other three protectors. In addition, the Richmar protector's percentage was significantly higher than that of the Century.

Table 50

ANOVA Repeated Measures Summary Results: Percent of Energy Absorbed, 1.14 kg Missile, Low Drop Height

Source	df	SS	MS	F	p level
Treatments	3	355.063	118.355	162.31	.0001
Blocks	2	.604	.302		
Error	6	4.375	.729		
Total	11	360.043			

Table 51

Analysis of Pairwise Differences (Scheffé): Percent of Energy Absorbed, 1.14 kg Missile, Low Drop Height

Style	JBI	Century	Richmar	FemGard
Mean (S.D.)	**76.37** (.70)	**78.80** (1.37)	**86.91** (.32)	**89.45** (.13)

Note. Means underscored by the same line not significantly different at $p < .05$.

Table 52

ANOVA Repeated Measures Summary Results: Percent of Energy Absorbed, 1.14 kg Missile, High Drop Height

Source	df	SS	MS	F	p level
Treatments	3	28.122	9.374	27.09	.0007
Blocks	2	.510	.255		
Error	6	2.076	.346		
Total	11	30.708			

Table 53

Analysis of Pairwise Differences (Scheffé): Percent of Energy Absorbed, 1.14 kg Missile, High Drop Height

Style	Century	JBI	Richmar	FemGard
Mean (S.D.)	93.99 (.29)	95.47 (.16)	96.14 (.96)	98.24 (.52)

Note. Means underscored by the same line not significantly different at $p < .05$.

Significant differences in the percentage of energy absorbed during the 2.30 kg low drop were found among the four protectors, $F(3, 6) = 213.74$, $p < .0001$, as shown in Table 54. Analysis of pairwise differences (Table 55) indicated that under these impact conditions, all pairs of means were significantly different, in the following order of decreasing energy absorption: FemGard, Richmar, JBI, and Century.

Table 54

ANOVA Repeated Measures Summary Results: Percent of Energy Absorbed, 2.30 kg Missile, Low Drop Height

Source	df	SS	MS	F	p level
Treatments	3	366.915	122.305	213.74	.0001
Blocks	2	.659	.330		
Error	6	3.433	.572		
Total	11	371.008			

Table 55

Analysis of Pairwise Differences (Scheffé): Percent of Energy Absorbed, 2.30 kg Missile, Low Drop Height

Style	Century	JBI	Richmar	FemGard
Mean (S.D.)	67.95 (.93)	72.84 (.58)	76.32 (.75)	83.14 (.79)

Note. All pairs of means significantly different at $p < .05$.

Relationships among protectors' energy absorption percentages for the high drop of the 2.30 kg missile varied somewhat from those observed for the low drop. While the ANOVA test revealed significant differences among protectors, $F\,(3, 6) = 21.38, p < .0013$ (Table 56), slightly different pairwise comparison results were identified (Table 57). As with the low drop, the FemGard protector still demonstrated the highest energy absorption values and the Century the lowest. At the high drop height, however, the FemGard also absorbed significantly more energy than the Richmar, and the JBI and Richmar's absorption percentages were not significantly different from each other as they had been at the low height. The JBI protector, however, did absorb a significantly higher percentage of the applied energy than the Richmar under these test conditions.

Table 56

<u>ANOVA Repeated Measures Summary Results: Percent of Energy Absorbed, 2.30 kg Missile, High Drop Height</u>

Source	df	SS	MS	F	p level
Treatments	3	265.030	88.343	21.38	.0013
Blocks	2	5.280	2.640		
Error	6	24.798	4.133		
Total	11	295.108			

Table 57

<u>Analysis of Pairwise Differences (Scheffé): Percent of Energy Absorbed, 2.30 kg Missile, High Drop Height</u>

Style	Century	Richmar	JBI	FemGard
Mean (S.D.)	**73.01** (1.71)	**78.23** (1.77)	**81.04** (2.02)	**86.00**(2.21)

(Underscores: Century–Richmar; Richmar–JBI; JBI–FemGard.)

<u>Note</u>. Means underscored by the same line not significantly different at $p < .05$.

Energy Absorption Discussion. While relationships among protectors changed somewhat as test set-ups were varied, several patterns were seen across experimental conditions based on the analysis of variance tests. First, the Century protector's best energy absorption performance compared with the other three protectors was observed with the lightest (.56 kg) missile. This closed-cell foam protector fared less well with the two heavier missiles, particularly in comparison with the FemGard and Richmar protectors. It is possible that whereas with the lighter missile the compression of the gases within the closed cells of the foam could absorb the kinetic energy of the impact, the heavier missiles fully compressed the gases thus altering the material's characteristics and capacity to absorb energy. Second, the JBI protector, while not particularly notable under the .56 and 1.14 kg test conditions, demonstrated its best performance in relationship to the other protectors during the 2.30 kg missile drops. Third, the FemGard and Richmar protectors generally exhibited the best energy absorption characteristics of the group, particularly in response to the heavier missiles. Overall, the closed-cell foam protector tended to perform better under the impacts of the lighter missile, while the rigid plastic protectors were particularly effective in absorbing energy associated with the impacts of the heavier missiles.

As hypothesized, the protectors as examined by the drop testing methods utilized in this study did vary in cushioning characteristics, both with regard to shock attenuation and to shock absorption. However, it must be emphasized that these findings should be interpreted only as a comparative evaluation of the materials and designs of the chest/breast protectors under these specific off-the-body research conditions, and no significance is to be placed on these results with respect to potential risk to human biological tissues.

Chapter 5

SUMMARY AND CONCLUSIONS

With the advent of legislation mandating equal access for both females and males to sports opportunities and an increasingly strong societal emphasis on physical fitness, female participation in all categories of active recreation including contact sports has increased dramatically. Competition for female athletic scholarships and the desire of women to excel in physical performance have contributed to a significant increase in the level and intensity of women's play in all sports, including those not traditionally categorized as "contact" sports. These trends have raised concern regarding the potential for injury to the female breast and the consequent need for protective equipment. Despite a lack of epidemiological evidence regarding the incidence and severity of sport-related breast injury, sportsmedicine professionals have advocated the use of chest/breast protectors by women in sports where there is significant risk of impact to the breast.

While breast protection for women is encouraged, the existing body of public domain research on protective body padding systems and their potentially positive or negative effects on athletic performance is almost nonexistent and does not include studies concerning breast protection. Athletes in all sports frequently resist utilizing protective equipment for fear that performance will be diminished due to the weight, restrictiveness, or physical and psychological discomfort that may be associated with its wearing. It is possible that negative attitudes toward protective equipment usage could be reduced if it were demonstrated that existing products do not significantly impair performance or comfort and may indeed enhance long-term sport success through reduction of breast injury and discomfort. A comprehensive examination of existing chest/breast protectors and their effect on performance and comfort is an important step toward safer contact sports participation for women. The purpose of this study was to determine the effect of wearing selected chest/breast protectors on measures of performance and comfort, and to determine the mechanical response of the protectors to applied impacts.

Four chest/breast protectors deemed to be the most typical in style and materials technology of currently available protective sports gear were selected for evaluation in this study. Three protectors, the FemGard Protective Bra, the JBI BreastGuard and the Richmar Chest Protector, are made of rigid molded polyethylene materials, and the Century Women's Rib Guard is constructed of flexible, closed-cell polyurethane foam.

The subjects in this study were ten females whose fitness histories included consistent weekly running mileage of between 10 and 40 miles during the year previous to the study. To evaluate differences among the control (no-protector) condition and the four styles of protectors, each subject completed the same 30 minute submaximal treadmill running protocol at approximately 70% of her VO_{2max} for each experimental condition on five consecutive days. Metabolic, temperature, and perceptual data were collected at five minute intervals during the treadmill run and following ten minutes of cooldown and rest.

To determine if protector wear exacted an additional metabolic cost for the specified workload, exhaled respiratory gases were analyzed to determine oxygen and carbon dioxide concentrations and thus establish the level of oxygen consumption associated with the wearing of each specific protector. To examine the effect of the chest/breast protectors on local skin temperatures, thermistors were used to measure skin temperature at two sites: 1) on the midline of the sternum between the two breasts; and 2) at the base of the left breast. To estimate the effect of the protectors on heat flow away from the body, temperature values were also obtained on the outer surface of the protector directly exterior to the two sites and the temperature differential between interior and exterior thermistor values was calculated.

Because perceptual data can be more sensitive than objective data in detecting significant differences in clothing comfort in moderate environmental conditions, and because subjective evaluation of comfort is the final answer to human comfort questions regardless of objective data, three perceptual scales were used to evaluate the perceived comfort of the chest/breast protectors. The "Local Thermal Sensation," "Perceived Local Skin Wettedness," and "General Comfort Sensation" scales were designed to provide a comprehensive description of the comfort of the protectors which included both discriminative and affective elements. Data were obtained at the same five minute intervals as objective temperature data during the exercise and cooldown periods.

To evaluate the effect of chest/breast protector usage on general agility, subjects completed the timed agility element of a standardized motor ability test in the control condition and while wearing each protector. The course required abrupt starts, stops, and direction changes as well as sliding chest-down on the floor under a low horizontal bar. Agility, metabolic, temperature, and perceptual data were analyzed for relationship to presence and style of chest/breast protector using repeated measures analysis of variance statistical tests.

The mechanical responses of the chest/breast protectors to a range of applied impacts were also examined. To assess shock attenuation and shock absorption characteristics, the vertical acceleration-time and force-displacement histories of a projectile during surface contact with each protector were analyzed using a guided drop test methodology. Missile mass and drop height were systematically varied to help assess the effect of test setup conditions on material performance. Graphic presentations accompanied by qualitative examination and interpretation of data across the entire time histories of the impact events were used to present and analyze the cushioning properties of the protectors.

Findings

The following findings represent the major results of this study:

1. The chest/breast protectors examined in this study did not significantly increase the oxygen consumption required for submaximal treadmill running.

2. Some but not all protectors produced significantly higher local skin temperatures than the no-protector condition during exercise. Higher temperatures were generally associated with protectors that covered a greater surface area of the torso such as the Century and Richmar, were composed of multiple plastic/fabric layers such as the JBI, fit more closely such as the JBI and Richmar, or were constructed of closed-cell foam such as the Century. The larger temperature differentials between the skin and exterior equipment surface observed for the Century and JBI protectors were most likely related to the use of closed-cell foam and multiple material layers in their design and construction.

3. During the post-exercise rest period, the significantly higher local skin temperatures and temperature differentials were generally associated with the closed-cell foam Century protector.

4. None of the protectors produced significantly higher ratings of local thermal sensation than the control condition during exercise. The closed-cell foam Century protector, however, was rated as feeling hotter than the rigid polyethylene JBI model. During the post-exercise rest period, higher thermal sensation ratings were associated with the closed-cell foam Century protector, a finding supported by objective temperature data.

5. There were no significant differences in perceived skin wettedness ratings among the protector and control conditions, either during the exercise period or post-exercise rest period.

6. Two protectors, the FemGard and the JBI, were assessed to be similar to the control condition on general comfort sensation during exercise. General comfort sensation ratings significantly lower than those of the control condition were associated with the Century and Richmar protectors, which covered more of the skin's surface area, were bulkier, and generally produced higher local skin temperatures. During the post-exercise rest period, only the highly

insulative closed cell foam Century protector was perceived as significantly less comfortable than the no-protector condition.

7. There was no decrease in general agility associated with chest/breast protector wear, as measured by the protocol used in this study. Course times for the one-piece polyethylene Richmar protector were significantly faster than those of the control condition.

8. The chest/breast protectors varied in cushioning properties, both in shock attenuation and shock absorbency, as evaluated by a drop testing method. The closed-cell foam Century protector generally showed better shock attenuation characteristics than the rigid polyethylene FemGard, JBI and Richmar protectors, while the rigid protectors generally demonstrated superior energ absorption. The nature of the relationships among protectors with regard to cushioning characteristics also changed in response to systematic variation of missile mass and drop height.

Conclusions

From the results of this study it was concluded that:

1. The female athlete who chooses to use a chest/breast protector to reduce the risk of breast injury and enhance her sense of aggressiveness can do so without eliciting a higher metabolic cost for a given submaximal activity.

2. While the occlusive and insulative nature of the chest/protectors evaluated in this study generally did produce higher local skin temperatures than the control condition during exercise, the subjects in this study did not perceive any of the chest/breast protectors to be warmer than the control condition. This suggests that protector use does not induce greater thermal discomfort sensations than non-use.

3. Despite the impermeable characteristics of the chest/breast protectors, their use does not necessarily foster the elevated sensations of skin wettedness that are generally associated with discomfort.

4. Chest/breast protective products with general comfort characteristics similar to those of the no-protector condition are available to women seeking the benefits of breast protection.

5. None of the chest/breast protectors evaluated in this study impaired performance on a standard agility course, suggesting that protector wear may foster feelings of invulnerability to discomfort and encourage more aggressive sports participation while simultaneously reducing the risk of breast injury.

6. Closed-cell foam protectors provide superior shock attenuation properties by spreading the change in momentum of the impacting object over a longer period of time. They, however, experience the greatest deformation during impact for the range of applied forces utilized in this study. Energy absorption properties are more desirable in comparison to the rigid protectors when missile mass is lighter.

7. While rigid polyethylene protectors attenuate shock in a more abrupt manner than closed-cell foam, they provide acceptable impact protection because they pose a direct barrier between the body and the impact, preventing tissue deformation and penetration. Their energy absorption properties are generally superior to those of closed-cell foam, particularly during impacts with higher mass missiles.

Recommendations

This study has provided a first and rather elementary look into the cushioning properties of one category of protective body padding for sport and the effect of protector wear on human performance. Many questions related to the need for and efficacy of protective equipment remain to be answered. The first issue emerged during the process of reviewing literature to support the study. Data regarding the incidence and severity of sport-related breast injury are virtually non-existent, yet the informal, anecdotal reports of women in contact sports suggests a worrisome frequency of at least minor trauma such as bruises. The following two research approaches could begin to provide a more accurate description of risk to the breast associated with sport participation. A cross-sectional epidemiological study in which women from a variety of sports are examined for breast trauma on a regular basis over the period of a playing season could provide significant insight into the actual prevalence, nature and severity of sport-related breast injury on a sport-by-sport basis. Since little is known about the cumulative effects of repeated microtrauma to breast tissue, longitudinally studying women in sports such as karate or ice hockey could help to illuminate health risks to the breast that may be associated with long-term participation in these contact sports.

The impact test method used in this study evaluated the mechanical responses of the various protectors to an applied impact. Given the simplicity of the method, it is not possible to determine the manner and extent to which the protectors are capable of reducing shock to underlying biological tissue. Future studies could incorporate an array of pressure sensors on the surface of the breast and torso under the protector to estimate how much of the impact force reaches the body and to describe the pattern with which the protector may redistribute the force over the chest wall. Data could be used to develop and refine chest/breast protector designs for greater efficacy and comfort.

Due to the positioning of chest/breast protectors on the torso near the shoulder joint, the size and rigidity of some models pose a possible restriction to arm mobility. Indeed, women who use protectors have complained of restriction of lateral arm flexion and an uncomfortable sensation of "cutting in" and chafing in the armpit area. Whereas this study evaluated the effect of protector wear on general body agility, potentially negative effects on arm mobility were not examined. Information regarding the arm range-of-motion characteristics of chest/breast protectors could help women in contact sports with high arm involvement select the most appropriate product for their particular sport.

Subjects in this study were selected to meet a basic criteria of physical conditioning and for their ability to complete the specified maximal, submaximal and agility test protocols. Less than half of the subjects had any type of previous involvement with the martial arts or other contact sports. The treadmill running protocol used in this study did not resemble the types of movement patterns, the non-cyclical changes in body position, or the non-steady-state levels of exertion that are typically associated with contact sports such as ice hockey, lacrosse, soccer, or karate. Future studies could benefit by the use of athletes skilled in these contact sports in research designs representative of the top two levels of the USARIEM clothing and equipment analysis model (Goldman, 1981). Level four projects could include small-scale studies of simulated, sport-specific tasks carried out in the field or gym by skilled subjects wearing the clothing/equipment ensemble. Level five projects could consist of clothing/equipment studies conducted during actual athletic participation or competition.

This study evaluated only one category of protective equipment--chest/breast protectors. Many other types of body padding are widely used for a variety of anatomical locations and sports by both men and women. Yet little data are available for these types of protective equipment documenting their efficacy in mediating impact, their success in reducing injury rates, and their effect on measures of performance. The approach to product evaluation utilized in this study needs to be extended to a wider range of products. Future research addressing these issues can contribute not only to improved protective gear design, but also to a lowering of the resistance athletes may feel toward incorporating protective equipment into their games.

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