A COMPARATIVE ANALYSIS OF SELECTED HEAT STRESS VARIABLES ASSOCIATED WITH TWO TYPES OF TURNOUT GEAR ENSEMBLES

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CHAPTER 1

INTRODUCTION

Although the average number of fire fighters who die in the line of duty has steadily decreased over the past twenty years, heat stress-related heart attacks continue to be the leading cause of such fatalities accounting for approximately half of the deaths (Washburn, LeBlanc & Fahy, 1997; and Fire Fighters Fatalities in the United States in 1997, 1998). Figure 1 shows the distribution of the 94 deaths by medical nature of the fatal injury or illness.

Figure 1 From United States Fire Administration Federal Emergency Management Agency. (1998, August). Fire Fighters Fatalities in the United States in 1997. (Contract No. EME-98-SA-0083). TriData Corporation: Author. P. 16. Adapted with permission of the Author.

It should be noted, however, that many of the individuals who suffered fatal heart attacks had experienced previous heart problems. In an effort to further reduce fire fighters' deaths, attention has been directed toward various strategies including initiating health and fitness programs, examining current screening processes, and studying existing fire fighter clothing.

Bone, Clark, Smith & Petruzzello (1994) have suggested that although the fire gear has played a role in reducing the percent of deaths and injuries from burns, it also may have exacerbated a problem that continues to plague fire fighters, namely heat stress. Typically, physical work in a hot environment results in a core temperature rise of 1°C to 1.5°C. In addition to the heat inherent to the fire fighting environment, the weight and stiffness of the personal protective equipment (PPE) that fire fighters wear imposes additional physical strain on the wearer, which causes an increase in the workload. An increased workload will shorten the time it takes a fire fighter to become fatigued, which in turn reduces the amount of time one can actually work in a hot environment. Turnout gear tends to contribute to heat storage because of its impermeability, weight and stiffness. The impermeable nature of the gear restricts dissipation of body heat. Therefore, higher work levels, heavier, stiffer clothing, and heavy equipment will result in a greater core temperature (Veghte, 1998).

Heat stress occurs primarily when the core temperature rises beyond safe limits, limiting the body's ability to compensate for increases in ambient heat and humidity (Kairys, 1992). It makes little difference whether the heat comes from outside the body or within, the body's temperature rises because it cannot dissipate the heat fast enough (Skinner, 1985). If the body temperature rises to a level of 39.5° C to 40° C (103° – 104° F), one is suddenly faced with cramps, skin rash, exhaustion, collapse, heat stroke or death (Veghte, 1998). Veghte, also indicates that a rectal temperature of 39° C (102° F) is used commonly as the upper tolerance limit.

Personal Protective Equipment (PPE) is designed to provide protection from environmental conditions encountered by fire fighters. The proper PPE worn by fire fighters responding to structural fires typically includes a turnout coat and trousers (known as bunker gear), station uniform, boots, helmet, gloves and self-contained breathing apparatus (Huck, 1986). A typical turnout gear ensemble may weigh as much as 22 pounds. The self-contained breathing apparatus (SCBA) may add another 30 to 33 pounds of weight. In addition, each fire fighter may transport 15-20 pounds of tools and equipment to a specific job.

Fire fighters generate a great deal of metabolic heat as a result of the combination of strenuous physical work and PPE. A protective ensemble which is uncomfortable or hinders physical performance may not be worn as intended in situations that fire fighters perceive as less dangerous, thus increasing the potential for injury.

Justification

It is anticipated that reduction of heat stress due to PPE will decrease the percent of heat stress-related heart attacks. It is also anticipated that lighter weight PPE will lead to a reduction of heat stress. Since heat stress-related heart attacks are the leading cause of fire fighters' deaths, examination of alternative turnout gear that differs in weight is important. Although numerous studies have addressed reduction of the thermal stress by using various combinations of materials, the weight of the ensemble has not been addressed as a major issue.

Results of this study should be useful to both manufacturers and users of turnout gear to evaluate their current turnout systems concerning thermal comfort. Valuable information should be gained through this study relating to the importance of garment weight to the thermal stress experienced by fire fighters.

Purpose

The purpose of this investigation was to compare the physiological and perceptual responses of subjects wearing two types of turnout gear while performing a typical fire fighting workload in controlled environmental conditions. The environmental chamber, available at Oklahoma State University in the Department of Design Housing and Merchandising, was used to conduct this study. Student fire fighters participated in a protocol that simulates moderate fire fighting work activity in two environmental climates.

Objectives

The following objectives were established:

1. Compare subjects' perceptual responses including thermal comfort, moisture, and an overall comfort rating and the rate of perceived exertion, while wearing the two test turnout ensembles, under two environmental conditions, and over time.

2. Compare subjects' physiological responses including skin temperature, tympanic (Tty) temperature, sweat rate, and heart rate while wearing the test turnout ensembles, under two environmental conditions, and over time.

Hypotheses

1. There will be no significant differences in subjects' perception of thermal comfort, moisture, overall comfort, and rate of perceived exertion by test turnout ensemble and by environmental conditions, over time.
2. There will be no significant differences in the subjects' physiological responses, mean skin temperature at three sites, mean weighted skin temperature, tympanic (Tty) temperature, sweat rate, and heart rate, by test ensemble, and by environmental conditions, over time.

Definition of Terms

The definitions of terms used in the study are listed as follows:

Moisture Barrier - The portion of the composite designed to prevent the transfer of liquids. The second layer in the turnout gear system. (NFPA 1971 Standard, 1997)

NFPA - National Fire Protection Association; a private sector, volunteer-based standard making organization, which develops guidelines related to fire protection and prevention. (NFPA 1971 Standard, 1997)

OSHA - Occupational Safety and Health Administration; a government based standard making body which develops public health and safety standards.

Outer Shell – The outermost layer of the composite with the exception of trim, hardware, reinforcing material and wristlet material. (NFPA 1971 Standard, 1997)

PAR-Q Test – Physical Activity Readiness Questionnaire - a prescreening standard for entry into low to moderate intensity physical activity programs. (Guidelines for exercise testing and prescription, 1991).

PPE – Personal Protective Equipment

SCBA – Self-Contained Breathing Apparatus

RPE – Rate of Perceivedl Exertion – a scale that provides a method to quantify subjects' perception of exercise intensity developed by Borg (1992).

Skin Temperature – Temperature of the skin at a given location.

Structural Fire Fighting – The activities of rescue, fire suppression, and property conservation in buildings, enclosed structures, aircraft interiors, vehicles, vessels, or like properties that are involved in a fire or emergency situation. (NFPA 1971 Standard, 1997)

Sweat Rate – The rate at which a body produces sweat.

Thermal Barrier – The portion of the composite that is designed to provide thermal protection. (NFPA 1971 Standard, 1997)

Thermal Comfort – The perceived comfort, which expresses satisfaction with the thermal environment. (Watkins, 1995)

Turnout Ensemble – Firefighters protective clothing consisting of coat, pants, boots, hoods, helmet, and gloves. (NFPA 1971 Standard, 1997)

Tympanic Temperature - Core temperature taken in the ear.

Vasodilation – Dilation of blood vessels near the skins surface. This allows the heat within the body to reach the outer surface where radiation, conduction, and convection can carry the heat away. (Watkins, 1995)

VO_2 max – Is the maximum volume of oxygen consumed by the body each minute during exercise, while breathing air at sea level. (Guidelines for exercise testing and prescription, 1991).

Limitations

1. The number of subjects used in this study will be limited to six male fire fighters between the age of 20-23, who pass a physical screening and a garment fit analysis.
2. The environmental conditions will be limited to the following two conditions, 72° ± 2° F and 50% ± 5% RH, and 72° ± 2° F and 20% ± 5% RH. These conditions will allow comparison with other studies.
3. Structural fire fighting gear will be limited to two types of gear that follow the NFPA 1971 Standard on Protective Clothing for Structural Fire Fighting 1991 edition.

Assumptions

The following assumptions were identified:

1. The devices used to measure dependent variables will be functioning to manufacturers' specifications.
2. The National Fire Protection Association (NFPA) Standard 1971 turnout gear is typical of gear used by Oklahoma fire fighters.
3. The protection quality of the test gear to meet or exceed a certain standard will not be addressed in this study.

CHAPTER 2

REVIEW OF LITERATURE

In evaluating PPE, it is necessary to consider multiple factors that contribute to the effectiveness of the system, i.e. the fiber and fabrics used in constructing components of the turnout gear, the garments made from these fabrics, the multiple garments comprising the ensemble, and the interaction between the ensemble and the wearer. Therefore, the review of literature covers the following topics: (1) history of standards on structural fire fighting turnout gear, (2) fibers and fabrics typically used in turnout ensembles, (3) physiological responses to hot environments, and (4) previous thermal comfort studies using turnout gear.

History of the Standards on Structural Fire Fighters Turnout Gear

The American National Standards Institute (ANSI) and the National Fire Protection Association (NFPA) were involved in the development of standards for protective clothing and equipment for structural fire fighting. In 1971, the NFPA Sectional Committee on Protective Equipment for Fire Fighters began work on developing a set of standards for protective clothing worn by structural fire fighters. However, it was not until 1973 that a tentative standard on protective clothing for fire fighters was released. The committee continued to work on this standard until it was fully developed and adopted in November 1975.

Early Standards

The original set of requirements for fire fighters' protective clothing was based primarily on minimum flame and heat resistance and other considerations necessary for fire fighters' protection (Stull, 1998). The goal of the standard was to insure that improved protective clothing for structural fire fighting was available for all fire fighters. It was intended to provide performance, rather than material requirements. In the past, each fire department often depended on the competence and ethics of the distributors and manufacturers to supply the correct gear. It was the committee's hope to develop a standard that would eliminate dependence on manufacturers and distributors with clear statements of the performance and test requirements to be used for protective clothing. Fire Departments were not required to use the standard, however, it was offered to regulatory agencies and jurisdictions as minimum acceptable standards (Standard on Protective Clothing for Fire Fighting, 1975).

The early standard was prepared by NFPA Sectional Committee on Protective Equipment for Fire Fighters, which reports to the Association through the Committee on Fire Department Equipment. Since 1975, the committee has become a full Technical Committee and was named the Technical Committee on Fire Service Protection Clothing and Equipment. In 1981, the committee decided to rework the 1971 standards and produce a document more usable by both the fire service and the protective clothing manufacturers. The new document was intended to serve as a minimum standard for fire officers and others responsible for purchasing or preparing specifications for protective clothing for structural fire fighting personnel (Standard on Protective Clothing for Structural Fire Fighting, 1981).

In 1986, the committee again revised the standards to include more performance requirements and fewer specifications. This version also included separate chapters on performance and testing. This edition increased the number of definitions to clarify terms used within the specifications, to make sure that everyone had a common understanding of the terms. It also included more requirements for the manufacturers to meet. The new standard included chapters on performance requirements indicating set standards that each component was required to meet. The standard was divided into design requirements, performance requirements, testing and inspection, and test methods. As each new revision was released, the new standard became more focused on the specifications and requirements necessary to provide total protection.

The 1991 revision incorporated third party certification, labeling, and listing for the protective clothing. Additional definitions and specifications were added to clarify existing standards. New chapters were added that addressed interfaced items such as protective hoods and wristlets. Appendix materials were developed on cleaning the garments and the evaluation of how materials affect heat stress (NFPA 1971 Standard on Protective Clothing for Structural Fire Fighting, 1991).

Current Standards

The most current edition of NFPA 1971 Standard on Protective Ensemble for Structural Fire Fighting was approved in 1997. This edition also includes the requirements for helmets, gloves and boots, which were previously contained in separate standards, (NFPA 1971, Standard on Protective Ensemble for Structural Fire Fighting 1997). The new version of the NFPA 1971 Standard on Protective Ensemble for

Structural Fire Fighting (1997), is now organized in the following manner. Chapter 1 covers the administration of the standard. Chapter 2 discusses the requirements of third-party certification. Chapters 3, 4 and 5 provides actual requirements for the elements of the protective ensembles, with chapter three discussing the labeling standards, chapter 4 discussing the design requirements, and chapter 5 containing both the performance and physical requirements. Each of these chapters is broken into sub sections that pertain to a particular component of the ensemble. All test methods are included in chapter 6. Chapter 7 contains the mandatory references to other standards. The NFPA 1971 Standard considers the performance of the ensemble, in providing minimum protection, more important than the actual design of the ensemble.

The NFPA 1971 Standard states that the personal protective ensemble should provide protection to the upper torso, neck, arms and wrists, excluding the head and hands (NFPA 1971 Standards on Protective Ensembles for Structural Fire Fighting, 1997). The ensemble should consist of a combination of an outer shell, a moisture barrier, and a thermal barrier. This combination can be configured as a single layer or in multiple layers. The moisture layer, the thermal barrier, or a part of the thermal barrier can be incorporated into the protective uniform worn as station gear and shall meet the standards specified in NFPA 1975, *Standards on Station/Work Uniforms for Fire Fighters*, (NFPA 1971 Standards on Protective Ensembles for Structural Fire Fighting, 1997). The outer shell is to provide resistance to flame and water, and provide protection against heat radiation. The moisture barrier is to protect the fire fighter from steam and chemicals, while the inner layer acts as an insulating medium against heat conduction (Reischl, Stransky, DeLorme, & Travis, 1982).

Each component must meet specific requirements to be approved. The NFPA 1971 Standard, (1997 edition), requires that the moisture barrier and thermal barrier components, and/or the materials that meet multiple performance requirements extend at a minimum to the neckline seam of the coat, and to within 7.62 cm (3 inches) of the bottom outer shell hem of the protective garment. The barriers should extend to within 2.54 cm (1inch) of the end of the sleeve, and be permitted to retract a maximum of 5.08 cm (2 inches). The standard requires that the barriers in the trousers extend to the waistline seam, and extend to within 7.62 cm (3 inches) of the bottom of the outer shell and be permitted to retract to a maximum of 10.2 cm (4 inch).

Specific requirements are given for trim as well. For the outer shell trim, a fluorescent or retroreflective trim that is at least 5.08 cm (2 inches) in width, must be permanently attached to the front of the coat. Two horizontal bands of fluorescent or reflective trim must be on the coat, one at the chest and one around the hem of the garment. The back of the coat should have two vertical bands, one located on the right side and one on the left side. The sleeves should have one band around the bottom edge. The requirements for trousers indicate that there should be two bands, one circling the bottom of each leg, and one circling the knee.

Other design requirements that are specified in the standard include that each coat must have protective wristlets permanently attached so as not to create a gap in thermal protection. Each coat must include a composite collar that is at least 10.2 cm (4 inches) wide and can be constructed from the outer shell fabric, moisture barrier fabric, and thermal barrier fabric, or a material that meets multiple performance requirements. Cargo pockets on the coat must be constructed to drain water and be able to fasten closed. Specifications for fasteners used within the ensemble are included in the standard.

NFPA 1971 Standard, (1997 edition), specifies the test that each component of the ensemble must meet before being approved. Table1 indicates the tests required for each component of the ensemble. While some tests are performed on individual components, others are performed on the ensemble as a composite. The composite, consisting of an outer shell, moisture barrier, and thermal barrier must be tested for thermal insulation by the TPP test to identify how much thermal protection a particular garment has. All other tests are conducted on individual materials to determine performance requirements for the given material.

Similar standards exist in Europe. During 1995, in response to a mandate from the European Economic Community, the European Norm EN469 was created. Like NFPA 1971, EN 469 set design and performance requirements for fire fighters' protective clothing (Stull, 1998). It is important to realize that most fire fighter clothing performance depends on the functional properties of three layers – the outer shell, and the thermal and moisture barriers. The EN469 Standard emphasizes test methods and performance standards for the outer shell and provides less performance standards for the other two components. Stull (1998) indicates that protective clothing standards do not address all aspects of clothing design and material performance, which are important to fire fighter protection. Stull's comparison of the NFPA 1971 Standard (1997 edition), the European Standard (EN469) is shown in Table 2 (Stull, 1998, p.34).

Table 1: Protective Garments Test Matrix

Test Materials or Component	Flame Resist. 6-2	Heat/ Thermal Resist. 6-6	TPP 6-10	Thread Melting 6-11	Tear Resist. 6-12	Seam Strength 6-14	Clean Shrink. Resist. 6-25	Water Absorb. Resist. 6-26	Water Penet. Resist. 6-27	Liquid Penet. Resist. 6-28	Viral Penet. Resist. 6-29	Corros. Resist. 6-30	Label Durab. 6-42	Retro-reflect. Fluor. 6-46	Overall Liquid Penet. 6-48	Breaking Strength 6-50
Clothing															X	
Composite			X													
Outer Shell	X	X			X		X	X								X
Moisture Barr.	X	X			X		X		X	X	X					
Thermal Barr.	X	X			X		X									
Winter Liner	X	X			X		X	X								X
Labels		X											X			
Other Textiles	X	X														
Thread				X												
Seams		X				X										
Hardware												X				
Trim	X	X														
Environmental Conditions																
Washing/ Drying 6-1.2	X		X					X	X	X	X	X				X
Room Temperature 6-1.3	X	X	X		X	X	X	X	X	X	X	X	X	X	X	
Convective Heat 6-15									X	X	X		X	X		

Source: NFPA 1971 Standards on Protective Ensemble for Structural Fire Fighting, 1998 Edition, p. 12.

Table 2
Comparison of Fire Fighter Protective Clothing Standards

Requirements	EN 469 (1995)	NFPA 1971 (1997)	ISO 11613 (proposed)	
			European approach	North-American approach
Overall garment				
Thermal protection	Optional		Optional	
Liquid-tight		X		
Composite				
Flame protection 1	X	X	X	X
Radiant protection 1	X	X	X	X
Liquid runoff	X		X	
Breathability	Optional		Optional	Optional
Outer Material (shell)				
Flame resistance 2	X	X	X	X
Heat resistance	X	X	X	X
Thermal shrinkage	X	X	X	X
Strength after heat exposure	X		X	
Cleaning shrinkage	X	X	X	X
Strength	X	X	X	X
Water repellency	X	X	X	X
Moisture barrier				
Flame resistance		X		X
Heat resistance	X	X	X	X
Thermal shrinkage	X	X	X	X
Cleaning shrinkage	X	X	X	X
Strength		X		X
Water resistance	Optional	X	Optional	X
Liquid resistance		X		
Viral resistance		X		
Liner (thermal barrier)				
Flame resistance	X	X	X	X
Heat resistance	X	X	X	X
Thermal shrinkage	X	X	X	X
Cleaning shrinkage	X	X	X	X
Strength		X		X
Other				
Seam strength		X		X
High visibility		X		X
Hardware		X		X
Label legibility		X		X

Note: (1) En 469 *and the European approach of* ISO 11613 *uses separate tests to measure thermal insulation from flame and radiant exposures, while* NFPA 1971 *and the North American approach uses a combined test to measure thermal insulation from both flame and radiant exposure.*

(2) *In* EN 469 *and the European approach of* ISO 11613, *the flame resistance test is conducted on both sides of the composite, while* NFPA 1971 *and the North American approach use testing of individual layers.*

Source: Stull, 1998. p.34

While it is difficult to make some comparisons between the EN469 and the NFPA 1971 Standard, the testing procedures are very similar. For example, NFPA 1971 requires a garment material to withstand 5 minutes in a 260° F oven without melting or igniting. The same tests are required for EN469 but the oven temperature is set at 180°F (Stull, 1998).

Other differences in the two standards include cleaning, thermal shrinkage, and highly visible materials. The most significant differences between EN 469 and NFPA 1971 is the amount of thermal insulation required (Stull, 1998). NFPA 1971 specifies approximately 45% more thermal insulation than EN469. NFPA 1071 also established requirements for knitted hoods and wristlets. Despite the differences in performance the NFPA 1971 Standards does not necessarily meet the EN 469 Standard (Stull, 1998). Stull, continues to say that industry argues that EN469 performance levels are not high enough for aggressive offensive fire fighting.

The International Standards Organization (ISO) has proposed a set of standards that incorporate aspects of both NFPA 1971 and EN469 to create a number of choices in the overall clothing performance requirements for fire fighter gear (Stull, 1998). The ISO standard is ISO Standard 11613.

Fabrics used in Structural Fire Fighting Turnout Gear

The Occupational Safety and Health Administration (OSHA) has set minimum standards for fire fighters' protective equipment. These standards are voluntary consensus standards formulated by organizations such as the National Fire Protection

Association as well as criteria developed by other governmental agencies (International Association of Fire Fighters, 1984). OSHA supplies a list of commercially available fabrics that are reported to meet OSHA and NFPA standards. This list specifies fabrics to be used in protective clothing, which can be broken into three components, outer shell, moisture barrier, thermal liner, or a combination of moisture and thermal barriers. The outer shell may be constructed from Nomex™ duck or duck coated with flame retardant (FR) Neoprene, Kevlar™ twill, or PBI™ or combined with Basofil®. Basofil® (para-aramid) fiber is a new advanced technology heat and flame resistant fiber. The Basofil® fiber has an innovative configuration of non-round fibers that help trap insulating air among its fibers. Basofil® fibers are blended with other aramid fibers to produce high performance and flame resistant fibers (BASF, 1997). Table 3 gives characteristics of the commonly used outer shell fabrics.

The best outer shell fabric depends on the individual fire departments needs. Each department needs to first perform a diagnostic of the environment in which the fire fighters work. Such a diagnostic should consider the following,

- number of calls made each year,
- the percentage of calls that involve structural fires, EMS related, or involve vehicle extractions
- the number of calls between the summer and winter
- the local climate
- the departments fire attack procedures

(Securitex, 1998)

Table 3
Commonly Used Outer Shell Fabrics

Brand Name	Fiber Content	Weight	Weave
Nomex IIIA®	93% Nomex , 5% Kevlar, 2% carbon fiber	7.5 oz/yd^2	Plain weave
Advance™	60% Kevlar, 40% Nomex	7.0 oz/yd^2	Ripstop weave
Delta T™	75% Nomex, 25% Kevlar	7.0 oz/yd^2	Twill weave
Kevlar/PBI	60% Kevlar, 40% PBI	6.2-7.5 oz/yd^2	Ripstop weave
Duralite™	50% multi-filament Kevlar, 25% multi-filament Nomex, 25% spun Nomex	6.0 oz/yd^2	Twill weave
Z200™	DuPont's Nomex Omega	7.5 oz/yd^2	
Basofil®	60% Kevlar, 40% Basofil	7.5 oz/yd^2	Ripstop weave

Source: Securitex, 1998

Nomex™ and Kevlar™ are aramid fibers that are the most important to the United States market. Aramid fibers were developed primarily for their inherent heat resistance and high strength. Aramid is a separate generic name assigned to aromatic polyamides because of their special properties. Aramid is divided into two subgenerics, meta-aramids and para-aramids according to the position of joining of the aromatic rings related to one another (Humphries, 1996). Nomex™ is also known as a meta aramid, where Kevlar is know as a para aramid fiber. The most important property of Nomex™ is its resistance to temperature and flame. Nomex™ fibers retain useful properties at temperatures up to 370°C (700° F). When exposed to heat, Nomex™ tends to char and not melt, and is self-extinguishing, giving off little smoke (Humphries, 1996). Kevlar™ also has excellent thermal properties; it can retain a high percentage of its strength after exposure to temperatures of 260°C (500°F). Kevlar™ is best known for its use in safety and protective clothing because of its high tenacity, flexibility, and resistance to stretching. PBI (Polybenzimidazole) is a fiber that does not burn or melt and will stay intact when charred. PBI will emit little to no smoke when exposed to flame. The only drawback is that PBI does lose some strength after extended exposure to ultraviolet light (Joseph, 1986).

Moisture barriers are typically the second layer in the turnout gear. The barrier consists of a film or coating which is either semi-permeable (breathable) or impermeable (non-breathable). The moisture barrier is the second line of defense in the fire fighters' gear. It provides some burn protection because of the insulation value of the substrate as well as the ability of the film coating to reduce the passage of hot gasses or liquids. However, its main function is to increase comfort by preventing liquids from reaching the skin of the fire fighter (Securitex, 1998). Moisture barriers fall into two categories, those based on a polyurethane film technology, like Vapro™, Breathe-tex™, and Aquatech™, and those based on a polytetraflourethylene film like Gore-Tex™ and Crosstech™. Materials may include Nomex™ laminated to Gore-Tex™, or coated with FR Neoprene.

Thermal liners are the third principal layer of the turnout gear. The thermal liner and moisture barriers are sewn together as a unit. The thermal liner is usually the layer closest to the body. The liners usually consist of non-woven felt or batting quilted or laminated to a woven lining fabric, which is usually referred to as face cloth. While others are made of fire resistant closed cell foam. The function of a thermal liner is to block the transfer of heat from the fire fighters environment to the body of the wearer. The thermal liner material may be an aramid needle punched fabric. Table 4 gives Characteristics of common components of thermal liners. The outer shell, moisture barrier and thermal liner comprises the gear required for each fire fighter to wear while on call. The difference between the gear is found in the fabrication and design of the gear. This in turn determines the weight of the gear, which can prove to be very important.

Table 4
Common Used Compositions of Thermal Liners

Face Cloth Fabrics	Thermal Barriers	Thermal Insulation Materials
Spun Nomex	Nomex	Non-Woven Batting - Nomex and Kevlar
Multi-filament Nomex	Kevlar	Close Cell Foam – polyvinyl chloride and nitrile rubber
Blends of Spun and Multi-filament Nomex	Ultrex	Basofil/aramid batting
Flame Retardent Cotton	SRS Rebound	
	Nomex Omega Turnout System	

Source: Securitex, 1998

Thermal Comfort Evaluation of Structural Fire Fighters Turnout Gear

Although information concerning the characteristics of fiber and fabric types is helpful in selecting specific textiles for use in PPE, fibers and fabrics alone cannot be used to predict performance of actual garments made of the same fibers and fabrics, particularly when worn with other garments in an ensemble. It is necessary therefore, to evaluate PPE systems using test methods and techniques that characterize the entire clothing/gear configuration. Various standard evaluation methods can be used. The interested reader can review the Huck dissertation literature review (1986) for a discussion of evaluation methods that use the thermal mannequin and the guarded hot plate.

The review for this study focused on evaluation methods that use human subjects. To understand the impact that temperature plays on the fire fighter, it is helpful to understand the methods of heat transfer and the human body's physiological responses to hot environments.

Heat Transfer Mechanism

As the core temperature rises, peripheral blood vessels dilate in an attempt to utilize the cooler tissues closer to the skin's surface to cool the core (Watkins, 1995). Rectal temperature is indicative of the core body temperature, and is subject to only slight fluctuations due to environmental and individual variations. When measuring core temperature a rectal probe has been the method used in the past. Because of recent advances in technology, tympanic thermometers offer an alternative method for measuring core temperature. Trombley (1996) found that tympanic thermometers reflect core temperature more efficiently. Tympanic thermometers offer other advantages as well. For example, they are easy to use, they produce readings in a few seconds, and they virtually eliminate the risk of cross-contamination (Trombley, 1996). Oral (Tor) and tympanic (Tty) temperatures were examined as alternatives for rectal temperature (Tre) as heat stress indicators (Beaird, Thomas, & Leeper, 1996). They concluded that there were no significant differences between Tty and Tre.

The average temperature of the body is dependent on a balance between heat produced by the body and heat lost to the environment. Veghte (1988) talks about conduction, convection, radiation and how each method relates to the clothing environment and fire fighters' response systems.. The environment may play a role as a heat source, but the environment can also play a role in transferring heat from the body to the surrounding environment. One way heat is transferred is through conduction. Conduction is a process of heat gain or loss that requires direct contact with another surface at a different temperature. "The role of heat conduction in bunker gear is usually underestimated and is significantly increased if protective clothing is wet or compressed" (Veghte, 1988, p.6).

Another method of heat transfer is that of convection. Convection depends on the movement of surrounding gases or liquids. In the case of fire fighters, this is usually hot air or water. "Convective air flow within layers of clothing, and its role in the mechanics of heat transfer, is one of the most overlooked considerations in the design or selection of most prototype clothing." (Veghte, 1988, p 7). The third type of heat transfer, radiation, heat is transmitted by thermal radiation. This is the most significant method of heat transfer for fire fighters. Thermal radiation is dependent on the temperature difference between two surfaces and the distance between them. As heat flows from warmer to cooler surfaces, it will flow quicker if there is a greater temperature difference between the two (Watkins, 1995). Therefore when the environment is hotter than the skin temperature, the body cannot dissipate heat by radiation. As the skin heats up to an average surface temperature of 33° C to 35 °C, sweating begins. After reaching the skin surface, the sweat begins to evaporate.

Evaporation occurs when liquids change into gases. The evaporation of sweat from the skin and respiratory passages is the only way to dissipate body heat when the environmental temperatures exceed the skin temperature (Veghte, 1988). Because of the construction of the turnout ensemble the evaporation process may be hindered, which can result in serious health and safety risks for the fire fighters (Reischl, Stransky, DeLorme, & Travis, 1982).

Physiological Responses to Hot Environments

The circulatory system has many functions. One function of the circulatory system is to protect the body from overheating. One such process of heat transfer is vasodilatation. Vasodilatation is controlled by the hypothalamus, which is located in the rear portion of the brain and acts as a thermostat for the body. It works as a control center for the central nervous system and pituitary gland to send messages to dilate or constrict the blood vessels near the skin surface in order to maintain normal body temperature. Vasodilatation is the expansion of surface blood vessels, which creates an increase in blood volume allowing heat to radiate from the surface of the skin.

The build-up of heat inside the PPE can cause serious health and safety problems for the fire fighters. With PPE, heat stress can become a problem in an environment that would not otherwise result in heat stress under average working conditions.

Metabolic heat is the heat produced and given off by human cells and organs (Goldman, 1990). The build-up of heat inside the PPE can seriously jeopardize the health and safety of the fire fighter (Reischl, et al., 1982). The PPE currently used provides protection against environmental hazards, however, it does not provide for adequate ventilation during times when metabolic heat production is increasing. PPE, because of its weight, stiffness, and extra bulk, adds to the increase of heat production.

Heat stress occurs when the body's temperature rises beyond safe limits. As the metabolic rate increases, the protective clothing begins to work against the body. The body begins to increase the production of unwanted heat, this unwanted heat could lead to sweating and fatigue. If sweating stops, or if sweat does not evaporate due to impermeable clothing, or if there is high relative humidity in the surrounding area, the bodies core temperature can rise to a level of 103°F to 104°F. At this point, medical difficulties are encountered and collapse is imminent. Therefore a temperature of 102.1°F is commonly considered the upper limit for non-working subjects (Veghte, 1988).

Heart rates of 180 beats per minute are usually considered the upper limits (Veghte, 1988). These rates will vary depending on the age and condition of the person. Fire fighters must indeed be physically fit to meet the increased circulatory demands associated with their profession. Therefore no PPE material or design can change the fundamental requirement that fire fighters be physically fit. However, well-designed PPE can minimize damage to a physically fit fire fighter from thermal and flame contact (Veghte, 1988).

Human Subject Testing

Reischl and Stransky (1980) tested a standard turnout coat using two different liners to evaluate ventilation characteristics of each. The experimental prototype incorporated features designed to enhance airflow through the clothing system. The protocol consisted of three test subjects; one male and two females. Subjects were given a medical examination and maximal stress test before conducting the research. The test was conducted in a controlled lab with a temperature of 72°F ± 1° F and 20-45% RH. The male subject walked on a motorized treadmill for 15 minutes with an increase of grade every three minutes, followed by a 6-minute recovery period. Because of the difference in the physical fitness level of the three subjects, the females only spent 9 minutes on the treadmill, compared to 15 minutes for the males. The results showed that subjects indicated a difference between the Gore-tex and Neoprene barriers. The Gore-tex barrier showed a lower metabolic heat build-up. The most drastic difference between the two barriers was in the sleeve area. At 90% max VO_2 the peak air temperature for Gore-tex is 88.1°F (31.2° C), while the Neoprene was 89.9°F (32.2° C). A *t*-test was used to determine the statistical significance between the different temperature locations (chest, back, arm, and leg). The arm and back regions showed a significant difference ($p<.05$). The small sample size (3) limited the external validity of the results.

Reischl et al, (1982) compared three new turnout gear prototypes to the existing NFPA 1971 Standard in the evaluation of heat dissipation characteristics. All four clothing systems were tested under full suit conditions. The tests were conducted in a temperature-controlled environment, at 22°C (72°F ±1°F), with RH varied between 40-60%. Oxygen consumption data and air temperature conditions inside the protective clothing and ambient air temperature were measured every five minutes throughout the test. The test included 2 male and 2 female subjects, each were given a medical examination and a maximal stress test. The protocol consisted of a 20-minute workout with increased workload every five minutes. The protocol consisted of an ergometer bicycle, to generate arm and leg exertion. Clothing air temperature was measured every five minutes. Two fans were located in front of the ergometers to maintain air flow through the test. A *t*-test was used to determine the statistical significance between the advanced prototype garments and the standard turnout gear. The mean garment temperatures for the three prototypes were significantly lower ($p<.05$) in comparison to the turnout gear. The arm region temperature was significantly lower in the three prototypes, while the chest region was not significantly lower. The temperature of the leg region was only significant in one prototype. Although the design of the new protective clothing provided a significant improvement in heat dissipation, the weight of the garment was a disadvantage.

Bone et al, (1994) conducted a study comparing subjects' heat stress when wearing the standard turnout gear to hip boots and station gear. The study was conducted under environmentally controlled conditions. Sixteen fire fighters were asked to walk on a treadmill for 15 minutes in each of the different clothing configurations. Each configuration was worn on separate days by each fire fighter. Configuration 1 consisted of a standard turnout gear. Configuration 2 consisted of hip boot and a full-length turnout coat. The third configuration consisted of bunker boots, bunker pants, and turnout coat. A self-contained breathing apparatus (SCBA) was worn with the hip boots and the standard gear. The face piece was modified to allow the collection and analysis of expired air. The results of the subjects' heart rate, rectal temperature, mean skin temperature and oxygen consumption was significantly greater with the standard gear than with the hip boots or station gear. This could be expected given the weight difference between the three configurations. The study does not indicate specific environmental conditions, nor does it indicate any statistical analysis.

Carter (1996) conducted two studies to look at the problem of heat stress. One study looked at how much physical stress was created when a fire fighter worked in turnout gear and SCBA. The second study examined a practical way to reduce heat stress during short recovery periods.

In the first study, five fire fighters completed 10-minutes of climbing stairs followed by a 10 minute rest period, in a controlled environment of 40°C with 70% RH.

In one trial, the fire fighters wore shorts and running shoes and in the other trial, they wore the full ensemble. The results showed a significant increase in physical stress on the fire fighters while wearing the turnout gear and SCBA. The study found that heart rate was approximately 35 beats/min higher in the turnout gear than in shorts. While wearing the turnout gear the fire fighters could not adequately cool their bodies, causing the core temperature to rise by 1.17° C during exercise and recovery. The most significant finding was that when the fire fighters worked in the turnout gear their core temperature increased by 63% of a degree C during the recovery period. During this recovery time the subjects sat down and did not remove their coats. After 10 minutes of rest the fire fighter was at a greater risk of heat exhaustion than at the start of the rest period.

The second study examined whether a more efficient cooling technique between work periods could decrease fire fighters' heat stress during repetitive work activities. Twelve fire fighters completed the work/ recovery trials under the same environmental conditions as in the previous test. After completing the work, fire fighters in one trial were allowed to unbuckle their coats during the recovery, while the fire fighters in the other trial took off their coats and sat in front of a fan. The results showed that by removing the coat and sitting in front of a fan, fire fighters experienced less physical stress. The heart rate, oxygen intake, skin temperature, and core temperature were all significantly lower when the fire fighters were allowed to remove their coat and sit in front of a fan. The results of the two studies indicates that wearing turnout gear does increase the physical stress experienced by fire fighters during heavy work in a hot environment. Carter also indicates that heat stress in fire fighters could be reduced by designing breathable fabrics with heat resistant properties, for use in turnout gear.

Carter, Banister, and Morrison (1997) also examined how protective clothing retards physiological recovery, and how more effective cooling during recovery periods can decrease the risk of heat stress during repetitive fire fighting activities. The result of this study indicated that additional physiological stress was caused by the impermeable nature of fire fighters' clothing, which prevented the evaporation of sweat, causing an increase in heart rate, oxygen consumption, skin temperature and core temperature. Therefore, recovery periods where the fire fighters have the chance to remove their coats will help in the reduction of heat stress. The study also suggest that short exposure to heavy work in a hot environment will not endanger a healthy fire fighter, where long term exposure can be dangerous.

Clark, Smith, Petruzzello, Bone (1998) follow up a study they did in 1994 in investigating the problem of heat stress induced by fire fighters tasks and compounded by turnout gear. The purpose of this study was to investigate the physiological and psychological responses of fire fighters to fire fighting tasks in a concrete burn building containing controlled fires. Fifteen fire fighters (age 30.3± 6.0years) were used in this study. Measurements of heart rate, tympanic temperature, and blood lactate levels were evaluated. Psychological measurements included rate of perceived exertion, perception of respiration, perception of thermal sensation, and perception of how they were feeling were collected. The test involved advancing a charged 1 ¾inch hoseline and chopping on a wood block located four feet above ground for eight minutes while inside the concrete burn building. Psychological measurements were taken before the tasks began.

Fire fighters were instructed to drag the hose throughout the rooms located on the second floor where the controlled fire was located. After eight minutes, another measurement was taken. The fire fighters then returned to the second floor and began chopping for eight minutes. The third and final measurements were taken following the last task. As expected the heart rate was higher after dragging the hose than the pre-exercise rate, and continued to rise during the second task. The same was found true for the tympanic temperature. The blood lactate was higher after the first task, but did not increase during the second task. Consistent with the heart rate and tympanic temperature, greater distress was evident following the second test than the first. All of the perception measurements increased from hose dragging to wood chopping. This data is constant with other data. It revealed that heart rate and core temperature were quite high after only eight minutes of the test. This is likely the result of increased thermal stress caused by a combination of a heavy workload and the inability of the body to cool itself because of the encapsulation of the turnout gear. The results of this study contained evidence to argue for higher fitness levels for fire fighters. This study contained no statistical measures.

Physical Fitness

Fitness and percent of body fat have been issues regarding the performance of fire fighters for the past twenty years. Because of this concern, several organizations have developed guidelines or standards regarding physical fitness or performance. Several studies have evaluated the effects of added weight on physical performance. These studies looked at the concept of extra weight affecting job performance. The results showed that adding additional weight while performing physical activity simulated the same physiological response as carrying additional body fat (Williford, &Scharff-Olsen, 1998). Willliford et.al used an example of two men both weighing 180 pounds, fire fighter A had 15% body fat while firefighter B had 25% body fat. This means fire fighter A had 27 pounds of fat and 153 pounds of lean body mass. Fire fighter B had 45 pounds of fat and 135 pounds of lean body mass. When you add the weight of the equipment fire fighters wear, fire fighter A would be wearing approximately 77 pounds while fire fighter B would be wearing 95 pounds. The results of this investigation found a statistically significant relationship between the percent of body fat and the time it took to perform the task. As the percent of fat increased, the amount of time it took to perform the task also increased. Therefore, in evaluating heat stress reduction, weight of the ensemble and the amount of body fat could be important. This research and others like it have prompted many organizations to implement physical fitness incentives.

CHAPTER 3

METHODOLOGY

The purpose of this investigation was to evaluate subjects' selected physiological and subjective responses associated with wearing two types of turnout gear representative of the United States fire fighters while performing a typical workload under controlled environmental conditions.

Sample

The convenience sample consisted of six male fire fighters, who passed a physical screening procedure, and a prescreening for fit of the test garments. Subjects were therefore approximately the same height and weight. Subjects were college student volunteers between the ages of 20-23, solicited from the Fire Protection and Safety Technology, through the posting of a flyer (Appendix A). Subjects completing the study were paid $100.00.

The nature of the experiment was explained to the potential subjects so that they understood what the study required of them. If they agreed to participate in the research study and if they fit the test clothing, they were asked to sign an Informed Consent form (Appendix B) as required by Oklahoma State University's Institutional Review Board (IRB) and to schedule the physical screening procedure. The physical screening procedure consisted of four processes, done sequentially, such that if a volunteer did not pass any one test, the physical screening process was terminated and the volunteer was not used as a subject. The four processes include the Physical Activity Readiness Questionnaire (PAR-Q test), a medical history analysis, a physical exam and a one-mile walk test taken from the Guidelines for Exercise Testing and Prescription (1991). The PAR-Q test (Appendix C) was used to identify potential subjects who should not participate in the physical activity of the test. If a potential subject responded "yes" to any question, they were eliminated from further consideration.

The second process was completion of a medical history analysis (Appendix D), which was administered by staff at the Wellness Center at Oklahoma State University. While at the Wellness Center, each volunteer also had tests to determine blood pressure, cholesterol, and percent body fat. A staff member from the Wellness Center reviewed the laboratory data and the medical history analysis for each individual to determine whether the volunteer should complete the last component of the physical screening procedure, the walk test.

The walk test was used to determine volunteer's maximal heart rate and predicted VO_2 max output. The one mile walk test consisted of walking (not running) as fast as possible around the inside lane of a 400 meter track. Each volunteer was equipped with a heart rate monitor, and the walk was timed. Predicted VO_2 max was determined using the following formula by Kline, Porcari, Hintermeister, Freedson, Ward, McCarron, Ross, and Rippe (1987, p.253).

$$VO_2 \text{ max (L.min-1)} = 6.9652 + (0.0091 \text{ x body weight in lb.}) - (0.0257 \text{ x age in years}) + (0.5955 \text{ x sex}) - (0.2240 \text{ x time}) - (0.0115 \text{ x HR})$$

where:

Sex = (male = 1, female = 0),
Time = minutes in decimal form, and
HR = ending heart rate.

The predicated VO_2 max must be converted to relative VO_2 max (ml/kg/min) in order to determine a subjects cardiorespiratory fitness (CRF) level, as given in Table 5.

The subjects were all found to be average, good, or high in relation to their level of fitness, as indicated with the box in Table 5. Approvals for all experimental procedures were obtained from Oklahoma State University Institutional Review Board (IRB) prior to the experiment (Appendix E).

Table 5
Norms for Maximal, Relative 02 Consumption ($VO_{2\ max}$) ML/KG/Min

	Fitness Category Men				
Age	Low	Fair	Average	Good	High
20-29	38	39-43	44-51	52-56	57+
30-39	34	35-39	40-47	48-51	52+
40-49	30	31-35	36-43	44-47	48+
50-59	25	26-31	32-39	40-43	44+
60-69	21	22-26	27-35	36-39	40+

Kline, G.M., Porcari, J.P., Hintermeister, R., Freedson, P. S., Ward, A., McCarron, R. F., Ross, J., and Rippe, J.M. (1987), Estimation of Vo_2 max from a one-mile track walk, gender, age, and body weight. Medical Science Sports and Exercise, 19:253-259.Reprinted with permission.

Once accepted, the subjects were scheduled for test sessions and provided directions regarding clothing, food and drink intake. Prior to the first test session, subjects reviewed the comfort ballot (Appendix F), the RPE (rate of perceived exertion) ballot (Appendix G), and the monitoring instruments. Each subject wore each test ensemble for each environmental condition, thus participating in four test sessions.

Testing and Evaluation

The testing of subjects wearing the turnout ensembles took place in an environmental chamber located in the College of Human Environmental Sciences at Oklahoma State University. The conditions were limited to the following two conditions, 72° ± 2°F and 50%±5% RH, and 72° ± 2°F and 20%±5% RH.

Variables

Controlled Variables

For the purpose of this study, the following variables were controlled: age between 20-23, gender, physical condition, physical activity, exposure time, and size. Each subject wore the same components; station uniform, gloves, hood, and self-contained breathing apparatus, in addition to the test garments. Subjects wore their own undergarments, socks and boots. The boots were rubber boots which all met NFPA specifications. The station uniform consisted of pants and long sleeved shirts made of 100% Nomex twill. Gloves and hood were provided to each subject. All components met or exceeded the NFPA standards.

Independent Variables

The independent variables in this study included two variations of turnout gear and two environmental conditions. Ensemble "A" was typical of structural fire fighting gear that met minimal NFPA 1971 standard. Ensemble "B" was a newer, lighter weight structural fire fighter gear. Table 6 provides the specific components of each ensemble and Figure 2 shows the design features of test ensembles.

Table 6

Structural Components of Test Turnout Gear

Component	Suit A	Suit B
Outer Shell	Nomex II	Basofil®
• Composite • Weight • Weave	100% Nomex 7.5 oz/yd^2 Plain	40% Basofil/60% Kevlar 7.5 to 7.8 oz/yd^2 Ripstop
Moisture Barriers	Poly/cotton Neoguard	Breathe-tex (E-89)
• Composite • Weight • Characteristics	Neoprene laminate /fire retardant poly/cotton 11.0 oz/yd^2 Nonbreathable	Microporus polyurethane film / E-89 67%Nomex and 33% Kevlar 4.0-4.5 oz/yd^2 Breathable
Thermal Barriers	100% REPR Nomex Quilt	Omni Quilt
• Weight • Face cloth • Batting	 100% Nomex Mulitple layers of Nomex	5.4 – 9.8 oz/yd^2 100% Nomex – ripstop Basofil® - spun lace
• Total Weight	12.6 lbs	8.6 lbs

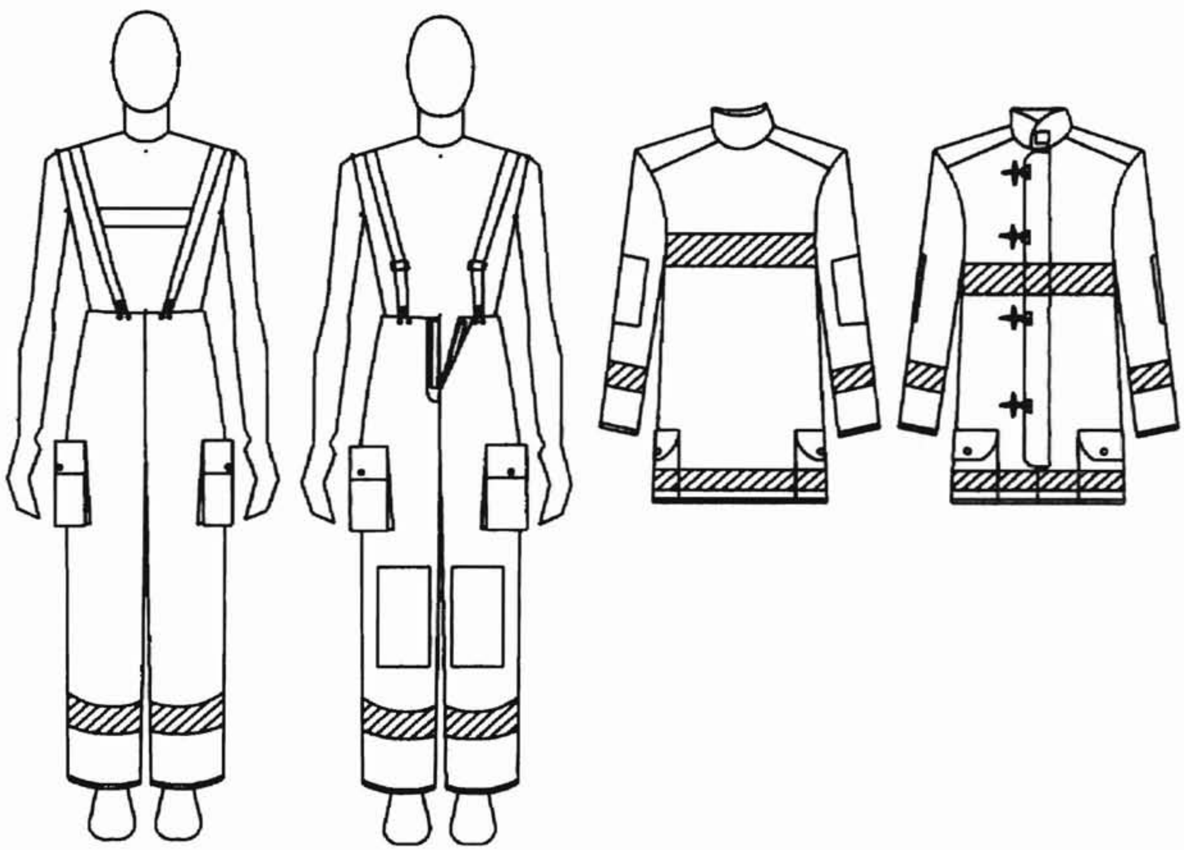

Figure 2. Illustration of suit A, front and back of pants and coat, Nomex II outer shell, poly/cotton Neoguard moisture barrier, 100% REPR Nomex Quilt thermal barrier.

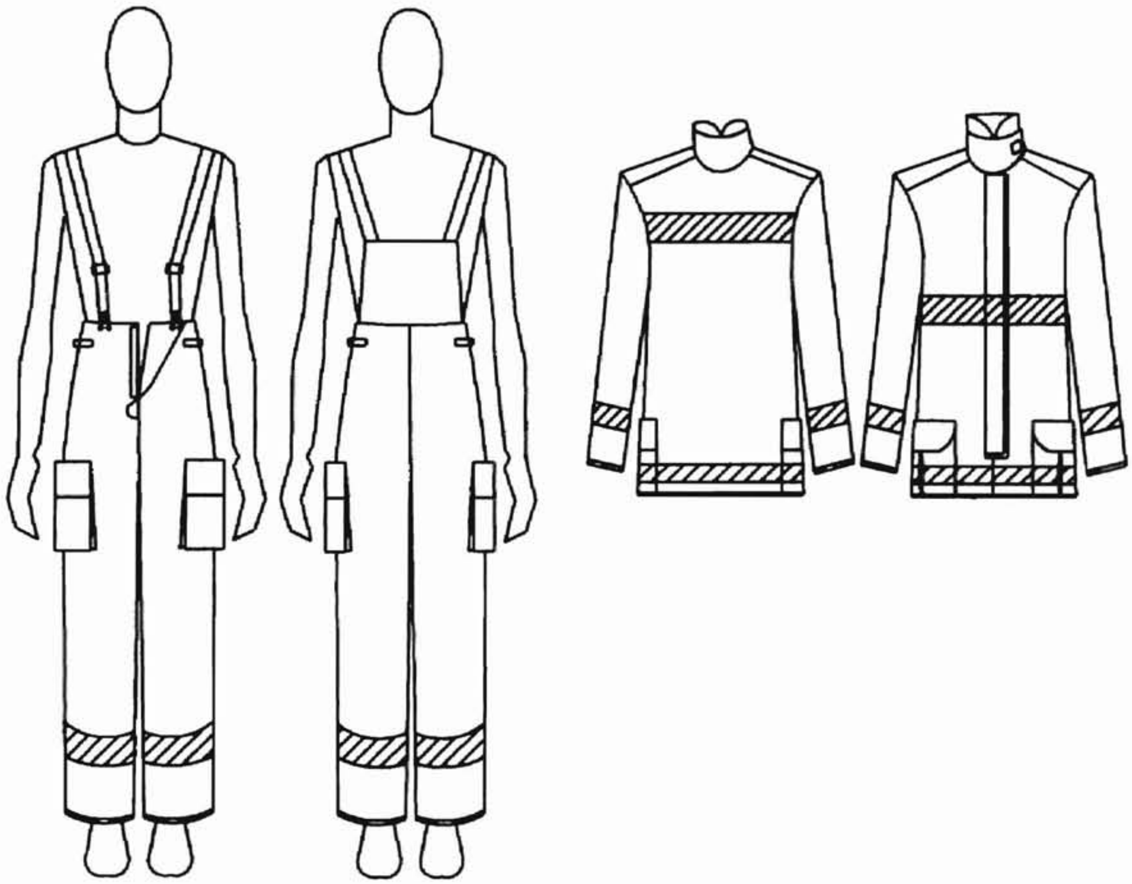

Figure 3. Illustration of suit B, front and back of pants and coat. The back of the pants has a bib to protect the lower back. The suit is Basifil® outershell with Breathe-tex (E-89) moisture barrier, and Omni Quilt thermal barrier.

The second independent variable was environmental conditions that were specified at 72° ± 2°F and 50%±5% RH, and 72° ± 2°F and 20%±5% RH, to facilitate data comparison with previous studies on fire fighting gear.

Dependent Variables

The dependent variables included subjects' core temperature, weighted skin temperature and three local skin temperatures, sweat rate at two locations, heart rate, and the effective measures of thermal sensation and comfort, moisture and other garment characteristics.

Core temperature was measured by a QuestempII datalogging personal heat stress monitor using a tympanic ear probe. An ear plug sensor was placed into the subject's ear canal to monitor the core temperature. The instrument stores and displays temperature data and sounds an alarm if a subject's core temperature exceeds the pre-set level. Data was collected every minute and was downloaded to a personal computer. Research has indicated that tympanic probes give fast readings without cross contamination. Beaird, Bauman, & Leeper (1996) found that there was no significant difference between rectal and tympanic temperature.

Skin temperature was measured with skin thermocouples, located on specific sites at the chest, arm, and leg. Mean skin temperature was computed using the formula given in Rohles, Milliken, and Krstic (1979, p.12),

$$T_{WMSK} = 0.50t_{skc} + 0.36t_{skl} + 0.14t_{ska}$$

where:

T_{WMSK}= weighted mean skin temperature,

t_{skc}= skin temperature measured at the chest,

t_{skl} = skin temperature measured at the lower leg, and

t_{ska}= skin temperature measured at the lower arm.

Thermocouples were taped with athletic tape to the three locations (Appendix H) and skin temperature was measured every minute. The data logger system, connected to a personal computer, was used to automatically record temperatures at predetermined. 1-minute intervals.

Two dew point capsules were taped onto each subject's chest and leg using athletic tape and vet wrap to secure the instruments to the subject (Appendix H). Dew point was measured via a dew point hygrometer system connected to a personal computer. Dew point was converted to sweat rate and recorded at 1-minute intervals.

Heart rate was determined every minute using a Polar Accurex II heart rate monitor. Subjects wore the transmitter around their chest and the monitor on their wrist. The monitor automatically recorded the information, which was downloaded into a personal computer.

A comfort ballot, developed by Hyun, Hollies, and Spivak (1991, pp.392-394), was modified to include only 16 of the original descriptors that related to fire fighters' clothing (Appendix F). Each subject was asked to verbally rate the intensity of their perception of each descriptor by responding to a 5-point intensity scale where 0 indicated not at all, 1indicated partially, 2 indicated mildly, 3 indicated definitely, and 4 indicated totally. Hollies conducted numerous comfort studies for a number of years continually refining his comfort ballot and response scale. Comfort ballots were completed by subjects immediately upon donning the gear and at five-minute intervals throughout each session.

The Borg RPE, rate of perceived exertion scale, (Borg, 1970, p. 93) was administered every three minutes, primarily as a safety measure. The subjects responded to the scale to indicate their perceived difficulty during the exercise test (Appendix G). Subjects were allowed to terminate the test if they felt they could not continue.

Experimental Design

The experimental design for this study was a 2x2 factorial arrangement of treatments in a randomized block design with repeated measures over time. This design was chosen in an effort to prevent a presentation bias for garment. Each subject completed four test sessions and each subject wore both test garments under both experimental environmental conditions. Due to time constraints and availability of the test gear, ensemble "A" test sessions were conducted first, then six weeks later, ensemble "B" test sessions were administered.

Test Protocol

Trial Procedure

A trial procedure was conducted to determine and correct any problems in the planned testing procedures. The environmental chamber was maintained at 72°F ± 2°and 50 % ± 5% RH environment. One male subject, not participating in the research, participated in this pilot study. While conducting the trial run, several comfort descriptors were found to be too similar in meaning to distinguish one from another. Binding, confining, tight and constricting were difficult to distinguish from each other. Impermeable was a term that was difficult for the pilot test subject to judge. Therefore, these descriptors were eliminated from the ballots. The trial run also uncovered changes that needed to be made pertaining to the fourth stage of the test, the recovery stage. To enable the investigator to monitor the heart rate wrist device during the recovery stage, the gloves were removed during this stage. In addition, the helmet, hood, SCBA and coat were also removed to aid in the cool down process.

Test

The testing protocol consisted of four stages: preparation, acclimation, exercise, and recovery. The first stage, preparation, lasted 15 minutes and took place in the laboratory. During this stage, the subject sat for fifteen minutes to allow his heart rate to become stable. During a subjects' first test session the subject read and signed the Informed Consent form and reviewed the procedures of instrumentation and protocol to be used in all of the test sessions. A sample comfort ballot was completed during this stage. During the other sessions each subject sat quietly for the first 15 minutes, allowing the heart rate to stabilize. The subject was then instrumented with the heart rate monitor, and dressed in the station pants and T-shirt.

Immediately upon entering the environmental chamber, the second stage, acclimation began. This stage lasted 15 minutes. The subjects, dressed in their station pants and T-shirt, were instrumented with the skin temperature thermocouples and sweat rate capsules. A chart mounted on the chamber wall indicated the proper thermocouple and sweat capsule placement (Appendix H). Skin temperature was taken at the chest, lower arm, and lower leg. The sweat rate capsules were located on the chest and arm. Skin temperature and sweat rate data were collected every minute. After instrumentation the subject was allowed to put on the shirt and hood. A tympanic ear probe was placed in each subject's ear and calibrated, using an oral thermometer. This took approximately 8-10 minutes. Core temperature was recorded at 1-minute intervals throughout the test session. The turnout pants, boots, jacket, helmet, SCBA air tank and facemask were donned. The list of descriptor terms for the comfort ballot was enlarged and placed on the wall in front of the subject. The first comfort ballot was administrated. Upon completion of the ballot, the subject hooked up his air hose and turned on the air tank, put on his gloves, and RPE was recorded.

The third stage, exercise, lasted 20 minutes. The subjects walked on a treadmill beginning at 3.3 mph and 0% grade. At 5-minute intervals, the grade was increased 3%. This physical activity was sufficient to induce sweating. Responses to the RPE was recorded every three minutes and the comfort ballot every five minutes. Subjects were asked to assess their perception of the intensity they experienced related to each descriptor. The investigator completed each ballot as directed by the subject.

Stage four, recovery, lasted approximately ten minutes. The investigator slowed the treadmill to 2.2 mph with a 0% grade, and the subjects continued to walk for ten minutes. Both RPE and comfort ballots were completed during recovery. During the recovery, the subjects were instructed to remove their gloves to enable the investigator to read the heart rate monitor. At one-minute intervals, the subject was instructed to remove certain pieces of equipment. The subjects were allowed to remove their helmet, facemask, and air tank at minute 32 of the test session. At minute 33 the subjects were allowed to remove their turnout coat to aid in the cooling down process. The subjects continued to walk on the treadmill until the ten minutes had ended.

At the end of the recovery stage, the subjects were allowed to remove the rest of their gear, all thermocuples, and sweat capsules. The tympanic and heart rate monitor remained on the subject, and the subject and the investigator left the chamber. The subject sat quietly in a chair until his heart rate fell below 100 beats/minute. At this time the instrumentation was removed and the subject was allowed to change into his own clothing. Two additional questions were asked (Appendix F, p 113) and water or Gatorade was given to the subjects. They were encouraged to continue to rest if needed. This protocol was followed for all four test sessions.

Early Termination

If any of the following criteria were present, the experiment was to terminated:

1. If the subjects' core body temperature rose above 38.2°C,
2. If the subject felt that he could not continue despite verbal encouragement,
3. If the subject's SCBA sounded a low-pressure alarm.

Although there were several times that subjects' SCBA sounded an alarm, since there was approximately 5 minutes of air left in the tank, the subject requested that they be allowed to continue the test session. Each subject was closely monitored for changes in behavior. All subjects completed each test session.

Statistical Analyses

The mean dependent measures were graphed over time. Analysis of variance tests (ANOVA) were performed to determine significant differences by ensembles and environmental conditions for the dependent variables over time.

CHAPTER IV

MANUSCRIPT 1

A COMPARATIVE ANALYSES OF SELECTED HEAT STRESS VARIABLES ASSOCIATED WITH TWO TYPES OF TURNOUT GEAR

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ABSTRACT

Fire fighting is strenuous work that can place extreme physical demands on fire fighters that perform their job in hot environments while wearing heavy protective clothing. Although turnout gear is necessary to protect the fire fighter from external heat and flame contact the protective clothing also increases the physical stress placed on fire fighters. Six male student fire fighters (mean age of 21.5 and a mean weight of 162.5 lbs.), wore two different turnout ensembles, composed of two different combinations, in two different environmental conditions, during a protocol of acclimation, exercise, and recovery/rest. The two turnout ensembles were compliant with NFPA 1971 Standards of Protective Ensembles for Structural Fire Fighting. Suit A consisted of Nomex II™ outer shell, poly/cotton Neoguard moisture barrier, and a 100% REPR Nomex Quilt thermal barrier. Suit B consisted of Basofil® outer shell, Breathe-tex (E-89) moisture barrier, and an Omni Quilt thermal barrier. The two environments were 22.2° ± 2°C and 50%±5% RH, and 22.2° ± 2°C and 20%±5% RH. Perceived sensation relating to overall comfort and exertion as well as skin temperature at three locations (chest, leg, and arm), sweat rate at two locations (chest and arm), core temperature and heart rate were assessed over time.

An ANOVA found significant three way interaction (environment x suit x time) for skin temperature at the arm. A significant environment by time interaction for sweat rate at the leg, and a significant suit by time interaction was found for skin temperature (chest and leg), mean weighted skin temperature, sweat rate (chest), RPE, and three comfort descriptors. All other variables showed a significant time effect. The results of this study suggested that differences in physiological measures were found for suit B. Unfortunately, the reason cannot be attributed solely to a weight difference since the suits also differed in multiple other ways. Suit B was lighter in weight and it contained a breathable liner system.

INTRODUCTION

While engaging in strenuous activities the body is continuously trying to maintain a constant body temperature or heat balance for critical bodily functions. This is accomplished by dissipating excess heat by one or a combination of methods of heat exchange including, evaporation, conduction, convection, and /or radiation. The turnout gear that fire fighters wear interacts with the thermoregulatory system of the human body, and can contribute to the sensation of discomfort and more importantly, heat stress for various reasons.

The purpose of this investigation was to compare the physiological and perceptual responses of subjects wearing two types of turnout gear while performing a typical fire fighting workload in controlled environmental conditions. Student fire fighters participated in a protocol that simulated moderate fire fighting work activity in two environmental climates.

A review of literature revealed that numerous studies have addressed reduction of the thermal stress by using various combinations of materials and components. Yet, the weight of the ensemble has not been addressed as a major issue. Therefore, the objectives of this study were to 1) compare subjects' perceptual responses including rate of perceived exertion, thermal comfort, moisture, and an overall comfort rating while wearing the two test turnout ensembles, under two environmental conditions, and over time and, 2) compare subjects' physiological responses including skin temperature, tympanic (Tty) temperature, sweat rate, and heart rate, while wearing the test turnout ensembles, under two environmental conditions, and over time. Null hypotheses were developed for each objective.

The results of this study should be helpful to both manufacturers and users of turnout gear to evaluate their current systems concerning thermal comfort. Valuable information should be gained through this study relating to the importance of garment weight to the thermal stress experienced by fire fighters. It is anticipated that reduction of heat stress due to turnout gear will decrease the percent of heat stress-related heart attacks. It is also anticipated that lighter weight turnout gear will lead to a reduction of heat stress. Since heat stress-related heart attacks are the leading cause of fire fighters' deaths, examination of alternative turnout gear that differs in weight is important.

BACKGROUND

Although the average number of fire fighters who die in the line of duty has steadily decreased over the past twenty years, heat stress-related heart attacks continue to be the leading cause of such fatalities, accounting for approximately half of the deaths. [1,2] It should be noted, however, that many of the individuals who suffered fatal heart attacks had experienced previous heart problems. In an effort to further reduce fire fighters' deaths, attention has been directed toward various preventive strategies including initiating health and fitness programs, and studying existing fire fighter clothing.

Fitness and body fat have been issues considered important to performance of fire fighters for the past twenty years. One study showed that adding additional garment weight while performing physical activity stimulated the same physiological response as carrying additional body fat. [3] The results of this study showed a statistically significant relationship between the percent of body fat and the time it took to perform the task.

Therefore, in evaluating heat stress reduction, the weight of the ensemble, weight of the firefighter and percent body fat can be important.

Because of this concern, several local fire departments have developed guidelines or standards regarding physical fitness. Research dealing with physical fitness has prompted many fire departments to implement physical fitness incentives.[3]

Bone, Clark, Smith and Petruzzello,[4] have suggested that although the fire gear has played a role in reducing the percent of deaths and injuries from burns, it also may have exacerbated a problem that continues to plague fire fighters, namely heat stress. The turnout gear currently used provides protection against environmental hazards, however, it may not provide for adequate ventilation during times when metabolic heat production is increasing. Typically, physical work in a hot environment results in a core temperature rise of 1°C to 1.5°C. In addition to the heat inherent to the fire fighting environment, the weight and stiffness of the turnout gear that fire fighters wear imposes additional physical strain on the wearer, which causes an increase in the workload. An increased workload will shorten the time it takes a fire fighter to become fatigued, thereby reducing the amount of time one can actually work in a hot environment.

Turnout gear also tends to contribute to heat storage because of its impermeability. The impermeable nature of the gear restricts dissipation of body heat. A protective ensemble which is uncomfortable or hinders physical performance may not be worn as intended in situations that fire fighters perceive as less dangerous, thus increasing the potential for injury. Therefore, higher work levels, heavier, stiffer clothing, and heavy equipment will result in a greater core temperature.[5]

Heat stress occurs primarily when the core temperature rises beyond safe limits, limiting the body's ability to compensate for increases in ambient heat and humidity. [6] It makes little difference whether the heat comes from outside the body or within, the body's temperature rises because it cannot dissipate the heat fast enough. [7] If the body temperature exceeds these limits, one is suddenly faced with cramps, skin rash, exhaustion, collapse, heat stroke or death.

As metabolic rate increases, protective clothing begins to work against the body. The body begins to increase the production of unwanted heat, this unwanted heat could lead to sweating and fatigue. If sweating stops, or if sweat does not evaporate due to impermeable clothing, or if there is high relative humidity in the surrounding area, the body's core temperature can rise to a level of 103°F to 104°F. At this point, medical difficulties are encountered and collapse is imminent. Therefore, a temperature of 102.1°F is commonly considered the upper limit for non-working subjects. [5]

Another area of concern among fire fighters is heart rate. Heart rates of 180 beats per minute are usually considered the upper limits. [5] These rates vary depending upon the age and condition of the person. Fire fighters must indeed be physically fit to meet the increased circulatory demands associated with their profession. Therefore, no turnout gear material or design can change the fundamental requirement that fire fighters be physically fit. However, well-designed turnout gear can minimize damage to a physically fit fire fighter from thermal and flame contact. [5]

Turnout Gear

The NFPA 1971 Standard states that the personal protective ensemble should provide protection to the upper torso, neck, arms and wrists, excluding the head and hands. [8] Each component must meet specific requirements to be approved. The ensemble should consist of a combination of an outer shell, a moisture barrier, and a thermal barrier. This combination can be configured as a single layer or in multiple layers. The moisture barrier, the thermal barrier, or a part of the thermal barrier can be incorporated into the protective uniform worn as station gear and shall meet the standards specified in NFPA 1975, *Standards on Station/Work Uniforms for Fire Fighters*. [8]

The outer shell is designed to provide resistance to flame and water, and provide protection against heat radiation. The moisture barrier is designed to protect the fire fighter from steam and chemicals, while the inner layer acts as an insulating medium against heat conduction. [9]

Moisture barriers are typically the second layer in the turnout gear. The barrier consists of a film or coating that is either semi-permeable (breathable) or impermeable (non-breathable). The moisture barrier is the second line of defense in the fire fighters' gear. It provides some burn protection because of the insulation value of the substrate as well as the ability of the film coating to reduce the passage of hot gasses or liquids. However, its main function is to increase comfort by preventing liquids from reaching the skin of the fire fighter. [10]

Thermal liners are the third principal layer of the turnout gear. This is usually the layer closest to the body. The liners usually consist of non-woven felt or batting quilted or laminated to a woven lining fabric, which is usually referred to as face cloth. The function of a thermal liner is to block the transfer of heat from the fire fighters' environment to the body of the wearer.

PROCEDURE

Subjects

Six male student fire fighters with a mean age of 21.5 and a mean weight of 162.5 lbs. were recruited. Each volunteer was required to pass a physical screening procedure, and a prescreening for fit of the test garments. Subjects were therefore approximately the same size and weight. Subjects were paid for their participation.

Test Facility and Environment

Testing took place in a controlled environmental chamber in two different environmental conditions. Each subject wore both turnout ensembles in both environments for a total of 4 test periods. The conditions were limited to the following two conditions, 22.2° ± 2°C and 50%±5% RH, and 22.2° ± 2°C and 20%±5% RH.

Test Ensembles

Each subject wore the same components; station uniform, gloves, hood, and self-contained breathing apparatus, in addition to the test garments. Subjects wore their own undergarments, socks and boots. The boots were rubber boots which all met NFPA specifications. The station uniform consisted of pants and long sleeved shirts made of 100% Nomex twill. Gloves and hood were provided to each subject. All components met or exceeded the NFPA standards.

Both variations of the turnout gear were worn by all of the subjects in both environmental conditions. Ensemble "A" was typical of structural fire fighting gear that met minimal NFPA 1971 standards. The coat and pants consisted of Nomex II outer shell with a poly/cotton Neoguard moisture barrier, and a 100% REPR Nomex Quilt thermal barrier. Ensemble "B" was a newer, lighter weight structural fire fighter gear. The coat and pants consisted of Basofil® outer shell, with a Breathe-tex (E-89) moisture barrier, and an Omni Quilt thermal barrier. Characteristics of the two different turnout gear used in this study are listed in Table 6 (p 35). The design characteristics of the two ensembles are detailed in Figure 2 and 3 (p.36-37).

Prescreening

The physical screening procedure consisted of four processes, done sequentially, such that if a volunteer did not pass any one test, the physical screening process was terminated and the volunteer was not used as a subject. The four processes included the Physical Activity Readiness Questionnaire (PAR-Q test), a medical history analysis, a physical exam and a one-mile walk test taken from the Guidelines for Exercise Testing and Prescription.[11] The one-mile walk test was used to determine a fitness level, by using a predicted VO_2 max.

To participate as a subject, each volunteer who successfully passed all screenings was categorized into the appropriate fitness category. The subjects used in this project were categorized as average, good, or high in relation to their level of fitness.

The dependent variables included subjects' core temperature, weighted skin temperature and three local skin temperatures, sweat rate at two locations, heart rate, and the effective measures of thermal sensation and comfort, moisture and other perceived exertion.

Core temperature was measured by a QuestempII datalogging personal heat stress monitor using a tympanic ear probe. Skin temperature was measured with skin thermocouples, located on specific sites at the chest, arm, and leg (Appendix H). Mean skin temperature was computed using the formula given in Rohles, Milliken, and Krstic.[12]

Two dew point capsules located on the chest and leg were used to collect dew point data which were converted to a local sweat rate for that site (Appendix H). Heart rate was recorded every minute using a Polar Accurex II heart rate monitor. Subjects wore the transmitter around their chest and the monitor on their wrist. Skin temperature, sweat rate, core temperature, and heart rate were recorded at 1-minute intervals and downloaded into a computer for subsequent analyses.

A comfort ballot, developed by Hyun, Hollies, and Spivak, [13] was modified for this research project to include only descriptors related to fire fighters' clothing. Subjects were asked to verbally rate the intensity of their comfort sensation by responding to a 5-point intensity scale. Comfort ballots were administered to the subjects immediately upon donning the gear and at five-minute intervals throughout each session. The Borg, Rate of Perceived Exertion (RPE) scale, [14] was administered every three minutes.

The experimental design for this study was a 2x2 factorial arrangement of treatments in a randomized block design with repeated measures over time. Each subject completed four test sessions and each subject wore both test garments under both experimental environmental conditions. Due to time constraints and availability of the test gear, ensemble "A" test sessions were conducted first, then six weeks later, ensemble "B" test sessions were administered. Subjects were picked at random and the environmental conditions were chosen by a flip of a coin.

Testing Protocol

The testing protocol consisted of four stages: preparation, acclimation, exercise, and recovery. The first stage, preparation, lasted 15 minutes and took place in the laboratory. The subject sat for fifteen minutes to allow his heart rate to become stable. A sample comfort ballot was completed during this stage. The subject then was instrumented with the heart rate monitor, and dressed in the station pants and T-shirt.

Immediately upon entering the environmental chamber, the second stage, acclimation began. This stage lasted 15 minutes. The subjects, dressed in their station pants and T-shirt, were instrumented with the skin temperature thermocouples and sweat rate capsules. Skin temperature was taken at the chest, lower arm, and lower leg. Sweat rate capsules were located on the chest and arm. After instrumentation, the subject was allowed to put on the shirt and hood. Tympanic ear probes were placed in the subject's ear and calibrated, this took approximately 8-10 minutes. The turnout pants, boots, jacket, helmet, SCBA and facemask were donned. The first comfort ballot was administrated before the subject hooked up the air hose. Upon completion of the ballot, the subject put on his gloves, and an RPE ballot was administrated.

The third stage, exercise, lasted 20 minutes. The subjects walked on a treadmill beginning at 3.3 mph and 0% grade (Figure 4). At 5-minute intervals, the grade was increased 3%. This physical activity was sufficient to induce sweating. The RPE ballots were completed every three minutes and the comfort ballot every five minutes. Subjects were asked to assess their perception of the intensity they experienced related to each descriptor. The investigator completed each ballot as directed by the subject.

Insert Figure 4

Stage four, recovery, lasted approximately ten minutes. The investigator slowed the treadmill to 2.2 mph with a 0% grade, and the subjects continued to walk for ten minutes. Both the RPE and comfort ballots were completed during recovery. During the recovery, the subjects were instructed to remove their gloves to enable the investigator to read the heart rate monitor. At one-minute intervals, the subjects were allowed to begin removing their helmet, SCBA and turnout coat to aid in the recovery process. The subjects continued to walk on the treadmill until the ten minutes had ended.

At the end of the recovery stage, the subjects removed the rest of their gear, all thermocouples, and sweat rate capsules. The tympanic probe and heart rate monitor remained on the subject, and the subject and the investigator left the chamber. The subject sat quietly in a chair until his heart rate fell below 100 beats/minute. At this time the instrumentation was removed and the subject was allowed to change into his own clothing. Final questions were asked and water or Gatorade was given to the subjects. They were encouraged to continue to rest if needed. This protocol was followed for all test sessions.

Due to the strenuous task each subject was asked to perform, subjects were allowed to request early termination. The following criteria were used to determine if the experiment should be terminated: 1) subjects' core body temperature rose above 38.2° C, 2) subject felt that he could not continue despite verbal encouragement, and 3) the subject's SCBA sounded a low-pressure alarm. The low-pressure alarm is designed to alert a fire fighter that their air supply is almost exhausted. Typically, when the alarm sounds a fire fighter has approximately 5 minutes of air left in the tank. There were several times the test could have been terminated, due to the low-pressure alarm. Once the air ran out the subjects unhooked the hose from the air tank and continued to breathe through the hose. One subject removed the mask to be able to breathe. Each subject was closely monitored for changes in behavior. All subjects completed each test session.

The mean dependent measures were graphed over time. Analysis of variance tests (ANOVA) were performed to determine significant differences by ensembles and environmental conditions for the dependent variables over time.

RESULTS

Each of the variables were graphed over time and were subjected to analysis. Results are given by dependent variables one at a time, with combined data in the following section.

Effect of Suit on Skin Temperatures

Chest

The ANOVA results indicated a significant time effect for the skin temperature taken at the chest location. In general, the beginning chest temperature of subjects wearing both suits was similar. Skin temperature of subjects wearing both suits increased throughout the exercise stage.

The results also indicated a significant suit by time interaction. It appeared that for subjects wearing suit B, the mean chest skin temperature was slightly higher for the first 21 minutes. From minute 21 to minute 30, subjects' chest temperatures in both suits were similar. During the recovery stage, chest skin temperature continued to rise for about 5 minutes, for subjects wearing suit A. In contrast, temperatures of subjects in suit B leveled off initially during recovery and then started to drop after 3 minutes. There was no significant environment by time interaction or environment by suit by time interaction for chest skin temperature.

Graphs of skin temperature at the chest for subjects in suits A and B and environments 1 and 2 are in Appendix I, (Figure 12,13, 14).

Leg

The ANOVA results indicated a significant time effect for the skin temperature taken at the leg location. The results also indicated a significant suit by time interaction during the recovery phase of the test session, with no significant differences during the actual test session. In general, the leg temperature of subjects wearing both suits was initially about 31° C and continued to rise until the recovery stage (min. 30–40). In comparing the two suits, at minute 31, subjects wearing suit A experienced an increasing leg temperature while in suit B leg temperature leveled off.

For temperature taken at the leg location there were no significant differences for the environment by time interaction, or the environment by suit by time interaction. Graphs of skin temperature at the leg for suits A and B and environments 1and 2 are located in Appendix I, (Figure 15,16,17).

Arm

The ANOVA results indicated a significant time effect for skin temperature taken at the arm location. ANOVA indicated a significant suit by time interaction.

In general, the arm temperature of subjects wearing suit A started out at about 32° C. With suit B, arm temperature was initially about 32.5° C. With suit B, arm temperature continued to rise to approximately 34.7° C, at which time temperature began to drop. In contrast, arm temperature of subjects wearing suit A rose and then fell at a slower rate.

There was also a three-way interaction between suit, environment and time. A graph of the three way interaction (Figure 21, Appendix I) shows that arm temperature for subjects in suit B began slightly higher than when subjects were in suit A for both environments. The results also show that at minute 19, subjects in both suits at 20% rh had a higher arm temperature that continued to be higher until minute 29. At this point, temperature of subjects in suit A continued to rise while temperature of subjects in suit B began to fall.

For temperature taken at the arm there was no significant difference for the environment by time interaction. Graphs of skin temperature at the arm for suits A and B and environments 1and 2 are located in Appendix I, (Figure 18,19, 20, 21).

Mean Weighted Skin Temperature

Mean weighted skin temperature was computed as given in Rohles, Milliken, and Krstic.[12] ANOVA indicated a significant time effect and a significant suit by time interaction.

Figure 5, indicates that subjects wearing both suits experienced increased mean weighted skin temperature over the experiment. During the recovery period, subjects wearing suit B experienced a greater and more rapid drop in skin temperature than subjects wearing suit A.

Graphs of mean weighted skin temperature for environments 1and 2 are in Appendix I (Figure 22, 23).

Insert Figure 5

Effect of Suit on Core Temperature

The ANOVA results indicated a significant time effect for core temperature. There was no significant differences found for suit by time, environment by time, or environment by suit by time. Core temperature gradually increased over time for subjects in both suits until the recovery period.

There was a trend for subjects in suit A to experience a higher core temperature than subjects in suit B as shown in Figure 6. Also, at minute 30, the treadmill speed and grade were reduced, however, core temperature continued to increase initially for both suits. These data confirm previous research findings.[4,15,16,] Graphs of core temperature for environments 1and 2 are in Appendix I, (Figure 24, 25).

Insert Figure 6

Effect of Suit on Heart Rate

The ANOVA results indicated a significant time effect for heart rate. There was no significant differences for suit by time, environment by time, and environment by suit by time.

Subjects wearing both suits experienced an increasing heart rate until the treadmill speed and grade were reduced. This was as expected due to the stress of the exercise protocol. As Figure 7 indicates, there was a trend for subjects in suit B to experience a lower heart rate during the exercise protocol.

Graphs of heart rate for environments 1and 2 are in Appendix I (Figure 26, 27).

Insert Figure 7

Effect of Suit on Sweat Rate

Chest

The ANOVA results indicated a significant time effect for sweat rate at the chest. The results also indicated a significant suit by time interaction during the recovery phase of the test session. As illustrated by Figure 8, there was a trend for subjects in suit A to have a lower sweat rate than subjects wearing suit B during the exercise protocol. However, when treadmill speed and grade were reduced, subjects in suit B experienced a greater increase in sweat rate than subjects in suit A. Both suit A and B have the same pattern of increase over time during exercise.

There was no significant difference for chest sweat rate for the environment by time interaction, or the environment by suit by time interaction. Graphs of chest sweat rate for environments 1and 2 are in Appendix I, (Figure 28, 29).

Insert Figure 8

Leg

The ANOVA results indicated a significant time effect for sweat rate at the leg. It also indicated a significant suit by time effect during the recovery phase. For sweat rate taken at the leg there was no significant differences for environment by suit by time interaction. It should be noted that sweat rate data at the leg location followed the same pattern as the sweat rate data for the chest, except a higher sweat rate was found for the leg (Figure 9).

Insert Figure 9

The ANOVA results indicated a significant environment by time interaction for the exercise study. The graph of leg sweat rate for environment by time (Figure 10), indicates that during the beginning of the exercise protocol the sweat rate data for both environments were similar. About midway, sweat rate at the leg for the 20% rh environment began to increase at a higher rate. The trend continued throughout the remainder of the session. Graphs of leg sweat rate for suits A and B for environments 1and 2 are in Appendix I, (Figure 30,31).

Insert Figure 10

Perceptual Data

<u>Rate of Perceived Exertion</u>

The ANOVA results indicated a significant time effect for the RPE. The results also indicated a significant difference for the suit by time interaction. There was no significant environment by time interaction nor environment by suit by time.

In general, subjects wearing both suits reported similar exertion levels throughout most of the test session (Figure 11). Minute 31 was the exception, at which time the exertion rate perceived by subjects in suit B, was less than the perceived exertion associated with wearing suit A.

Insert Figure 11

Comfort Ballot

The comfort ballot incorporated sixteen descriptors including heavy, damp, dry, and hot. Each subject was asked to rate each descriptor using a 5-point response scale. A rating of 0 indicated the subject did not perceive the given descriptor. A rating of 4 indicated the subjects perceived the descriptor totally. Individual ANOVAs were computed for each descriptor. Only three had a significant suit by time interaction. These included absorbent, constricting, and dry. All descriptors showed a time effect (Table 7). Despite the significant findings, examination of the data in Table 7 or in Figures 32-47 in Appendix I, does not provide clear meaningful trends for many of the descriptors by time or for the three significant suit by time interactions.

Insert Table 7

DISCUSSION AND SUMMARY

Physiological Data

When comparing the skin temperature at chest, leg, and arm locations, a similar pattern existed. Namely, subjects in suit A began with a similar or slightly lower skin temperature than subjects in suit B. By the end of the test, skin temperature at all three locations were higher for subjects in suit A as compared to subjects in suit B. An ANOVA found this to be a significant difference at the $p<.05$ level. The weighted mean skin temperature followed a similar pattern, with subjects in suit A experiencing a lower weighted mean skin temperature in the early part of the test, and rising throughout the exercise session. During the recovery period, the subjects' temperature while in suit A continued to rise before dropping.

It is interesting to examine the skin and core temperature data for both suits. Notice that although not significantly lower, there was a trend for subjects in suit B to experience a lower core temperature over the experiment, as well as a significant skin temperature by time effect for all locations. Skin temperature during recovery was lower for subjects in suit B for all four skin temperature measures.

Examination of heart rate data shows subjects in suit B experienced a lower heart throughout the exercise period. Examination of sweat rate data showed subjects wearing suit B experienced a higher sweat rate than subjects wearing suit A. Thus, subjects in suit B tend to have a lower core temperature, a lower heart rate (during exercise) and a higher sweat rate. Suit B was a lighter weight suit with a breathable liner, where suit A had a non-breathable liner. The composition of these two liners are very different in that suit A 's liner was made of Neoprene laminate/fire retardant poly/cotton which weighs 11.0 oz/yd^2, and suit B's liner consisted of a microporus polyurethane film/ E-89 which weighs 4.0-4.5 oz/yd^2. Even though this study found no significant differences in heart rate or core temperature by suit, with a larger sample size the results might well be different.

Perceptual Data

Results of analysis of variance for perceived comfort indicated a significant suit effect for three of the 16 comfort ballot descriptors: absorbent, constrictive, and dry. For the descriptors constrictive and absorbent, suit B was more absorbent, and less constrictive, at the beginning, but as the session progresses it is difficult to determine which suit was perceived as more absorbent or less constrictive. Garment A was also rated the driest of the two suit treatments.

There was a significant time effect for 13 of the comfort descriptors: breathable, clingy, clammy, comfort, damp, flexible, heavy, hot, snug, stiff, thick, warm, and wet. For the descriptors snug and stiff, there was a slight change in the intensity over the course of the exercise. Despite the significant findings, examination of the data does not provide clear meaningful trends for many of the descriptors by time.

There was a significant time effect for the rate of perceived exertion. The subjects perceived an increased intensity level throughout the test session with a decrease during the recovery. This was as expected.

CONCLUSION

The results of this study suggested that differences in physiological measures were found for suit B. Unfortunately, the reason cannot be attributed solely to a weight difference since the suits also differed in multiple other ways. Suit B was lighter in weight and it contained a breathable liner system. Future research that could focus on one factor at a time would be helpful to be able to pinpoint the reason for the observed differences.

The results of the rate of perceived exertion clearly indicated that no differences were attributable to suit. Thus, even though some physiological measures were significantly different by suit, subjects could not perceive the difference.

Interesting results have come out of this research. Several suggestions to consider for future research would include; increasing the sample size and repeating the test protocol might show more significant differences between the two suits. Repeating the same protocol, but increasing the time of the exercise session. Another idea would be to incorporate exercise that would also use the upper body as well as walking on the treadmill to simulate the typical work produced by the fire fighter. The final suggestion would to examine if gender differences would be present.

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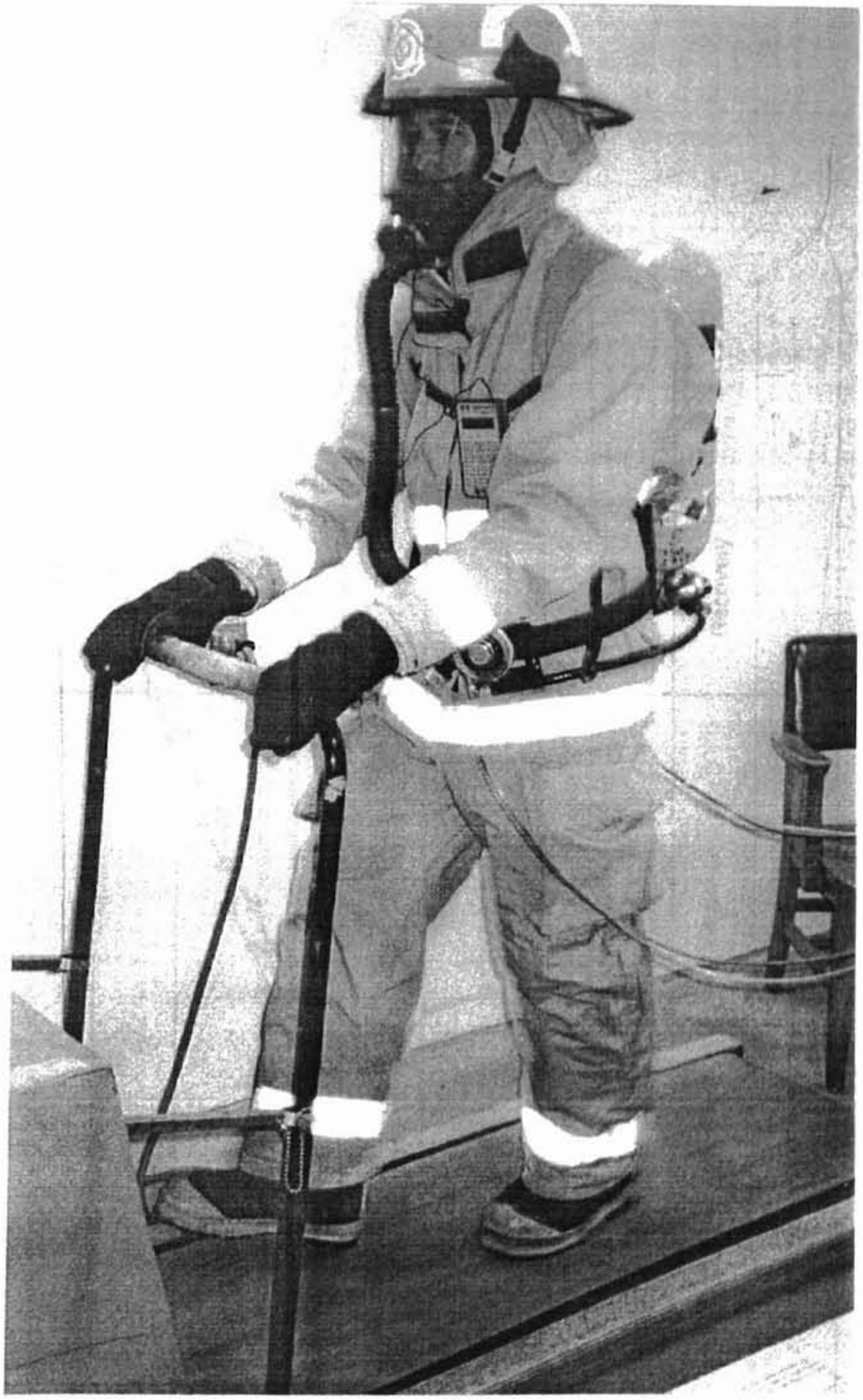

Figure 4: Subject fully instrumented, while walking on a treadmill

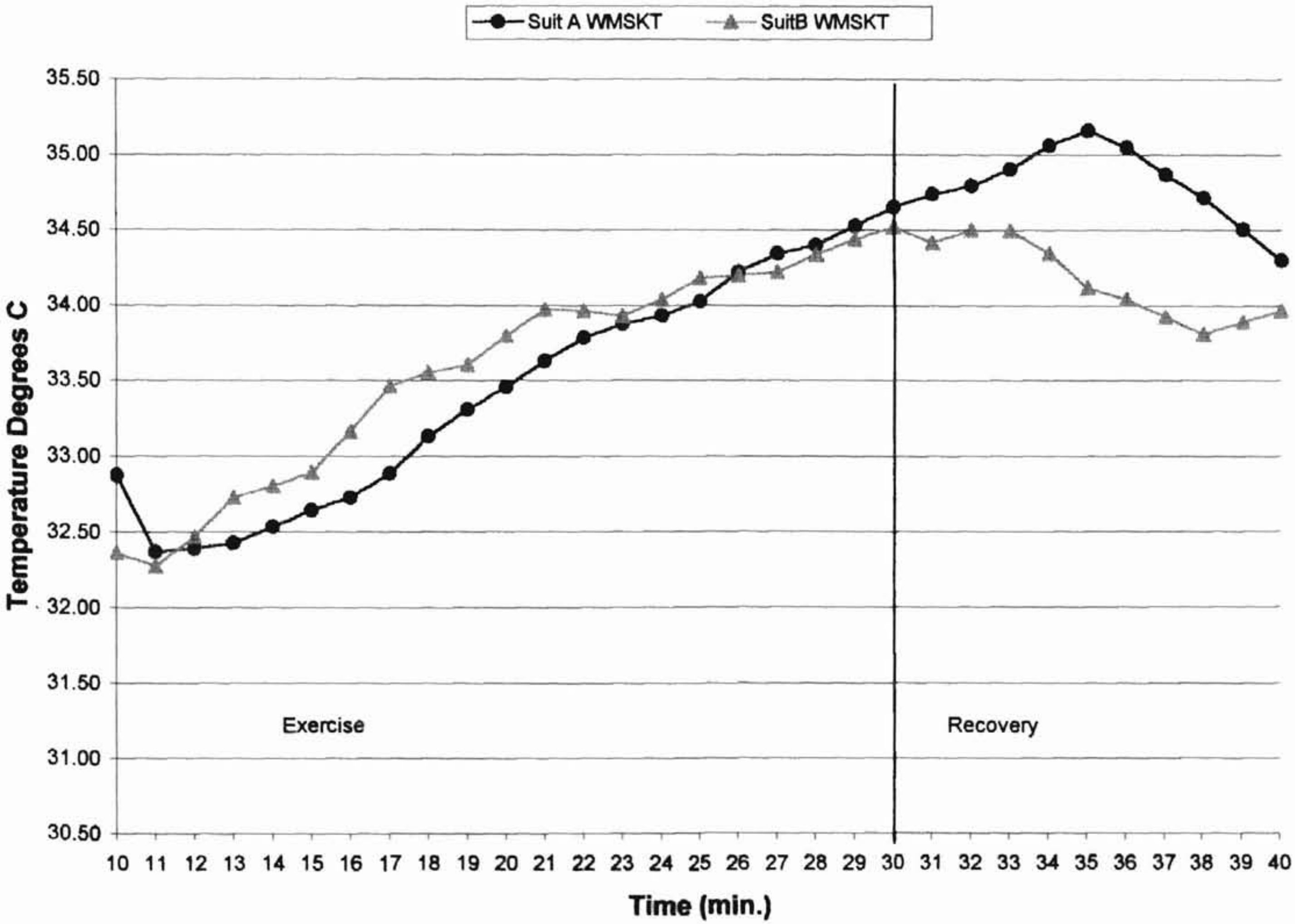

Figure 5: Mean Weighted Skin Temperature for suit A and B over time.

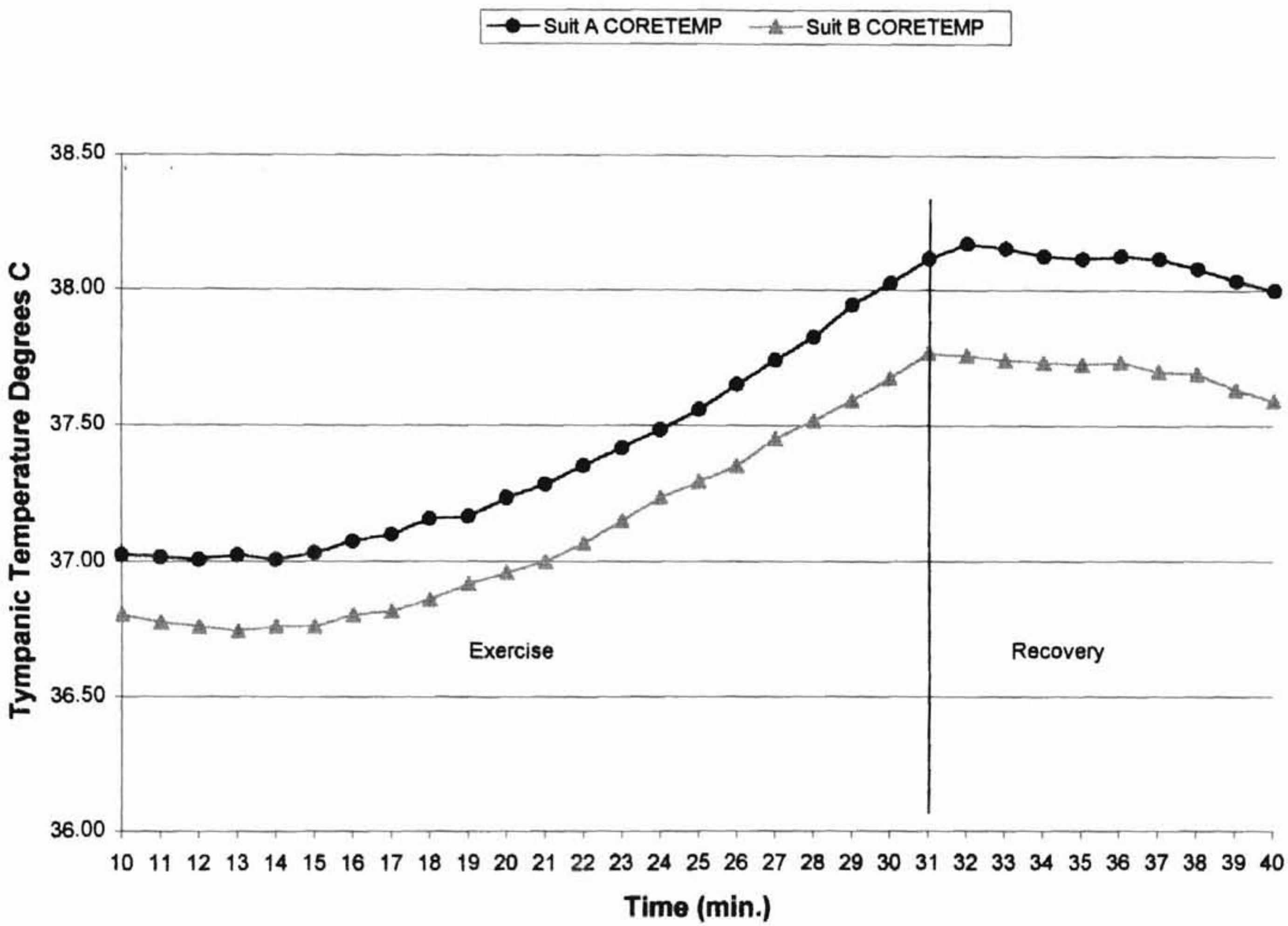

Figure 6: Mean Core Temperature for suit A and B over time,

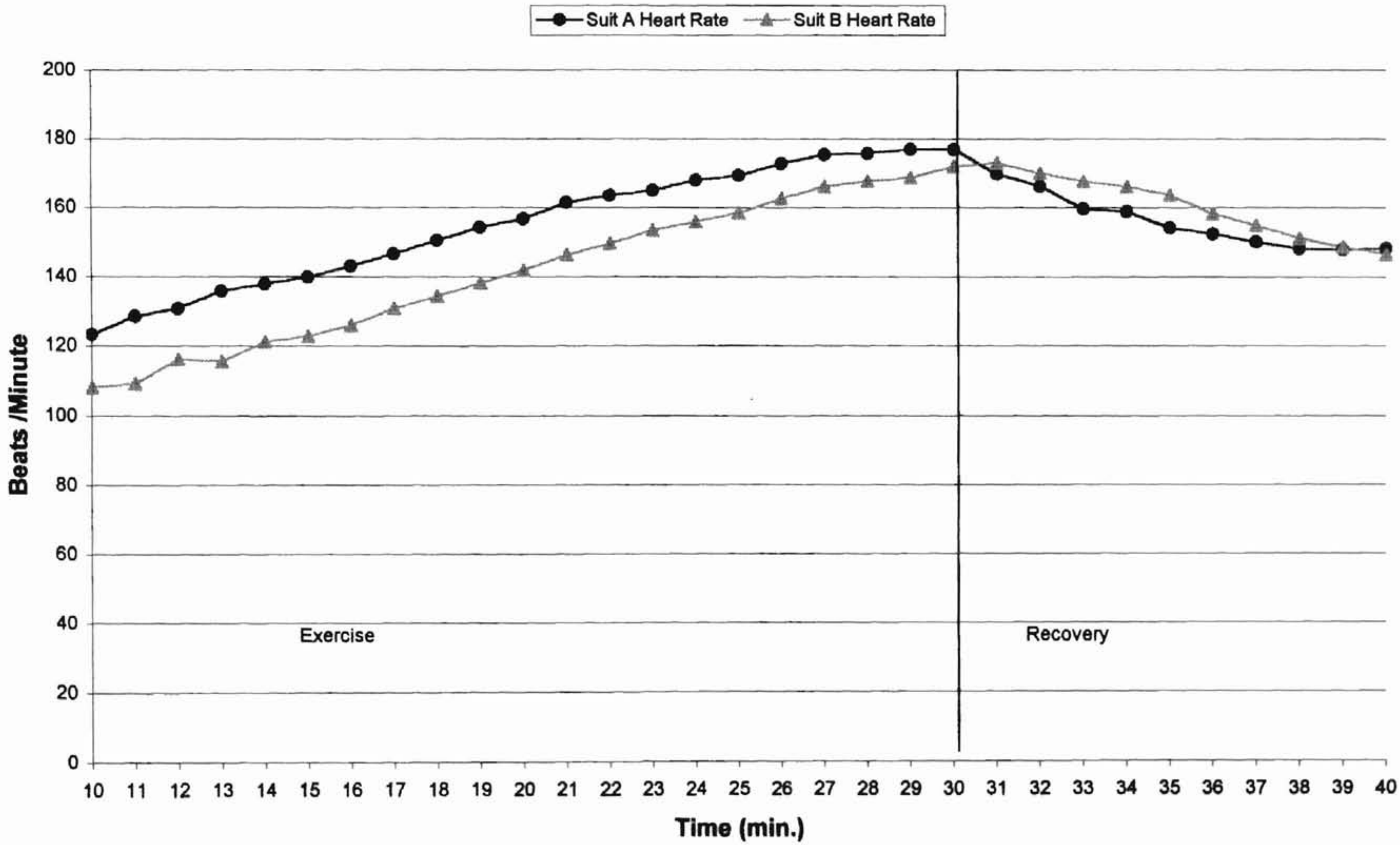

Figure 7: Mean Heart Rate for suit A and B over time,

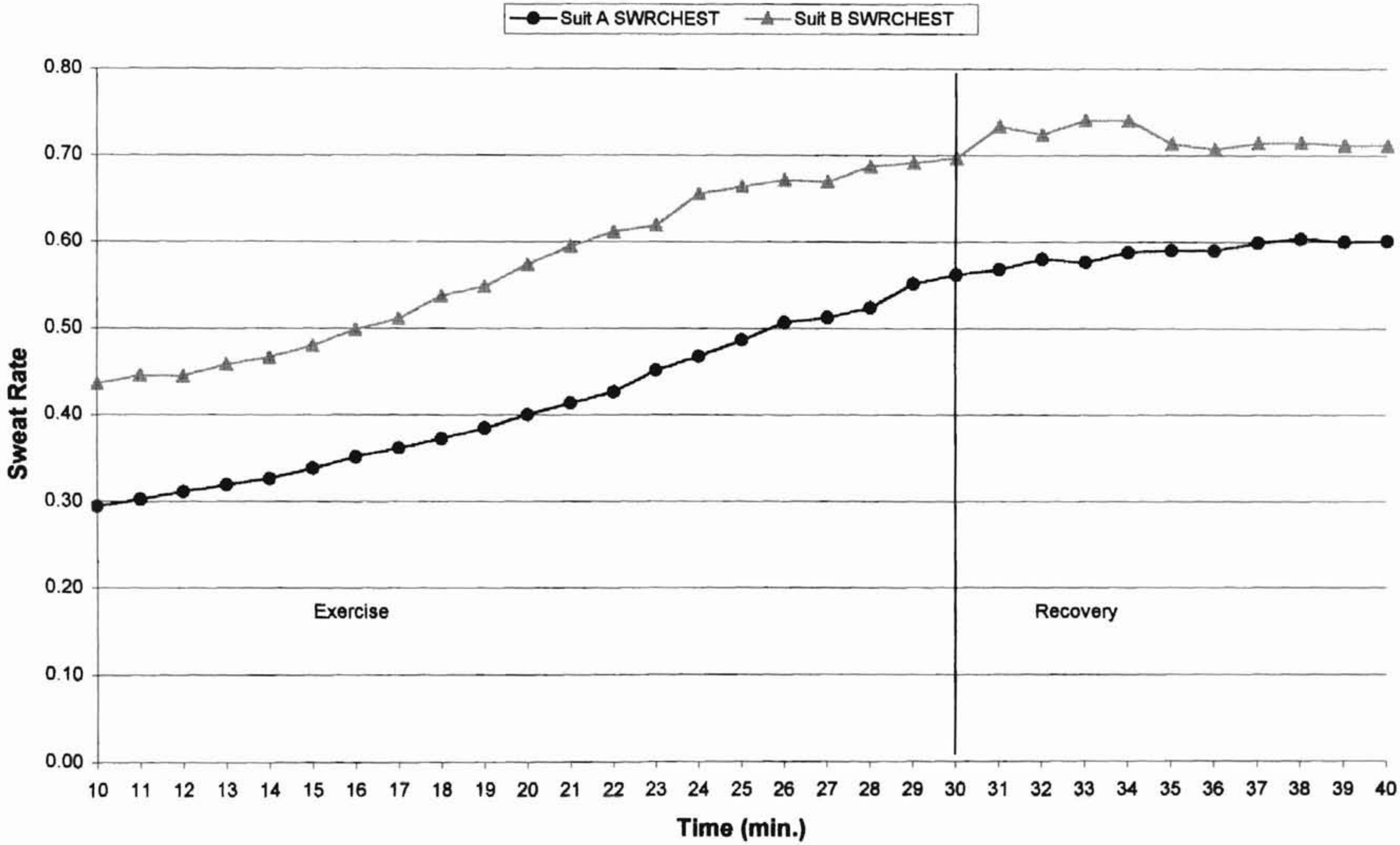

Figure 8: Mean Sweat Rate for chest in suit A and B over time.

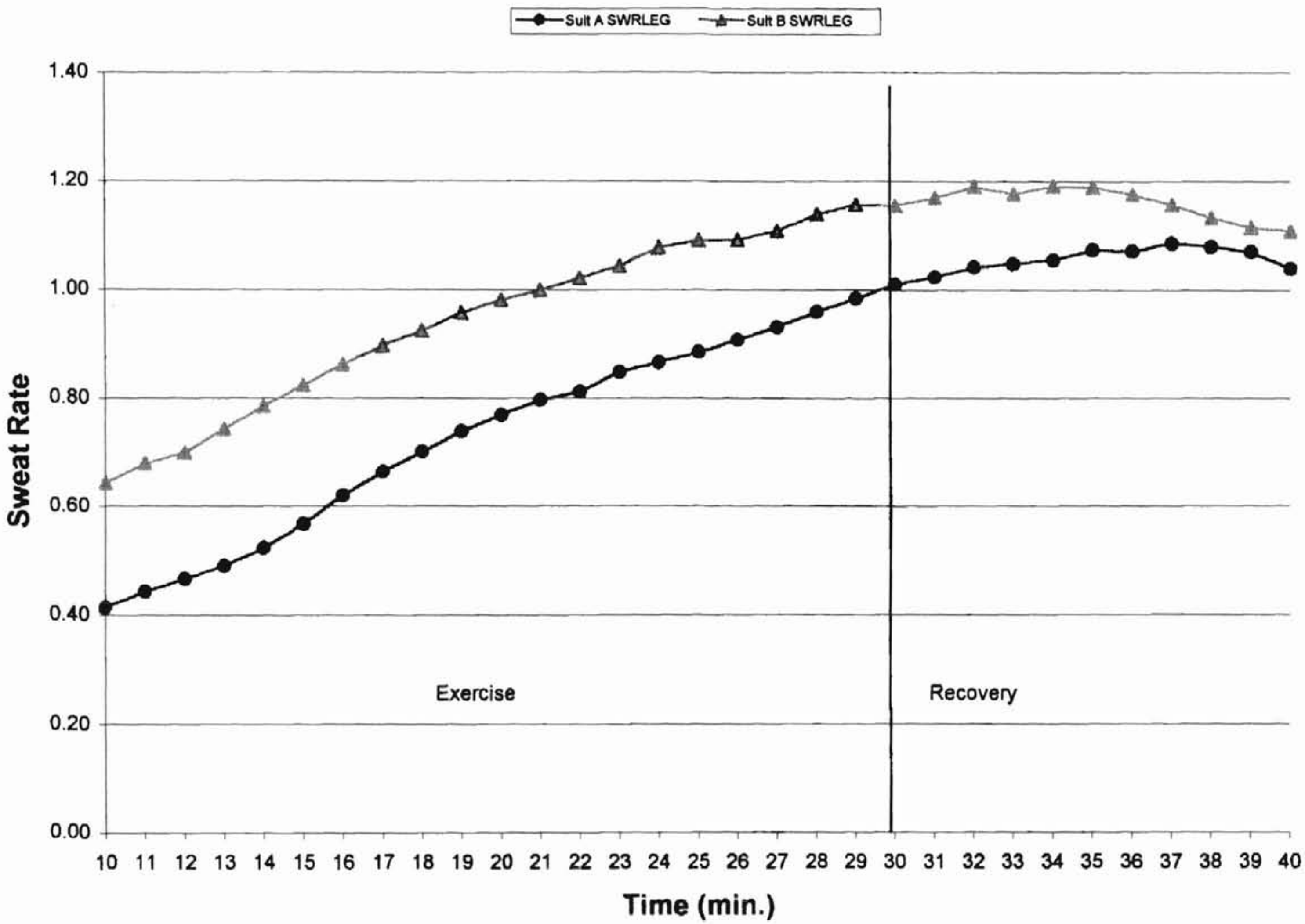

Figure 9: Mean Sweat Rate for leg in suit A and B over time.

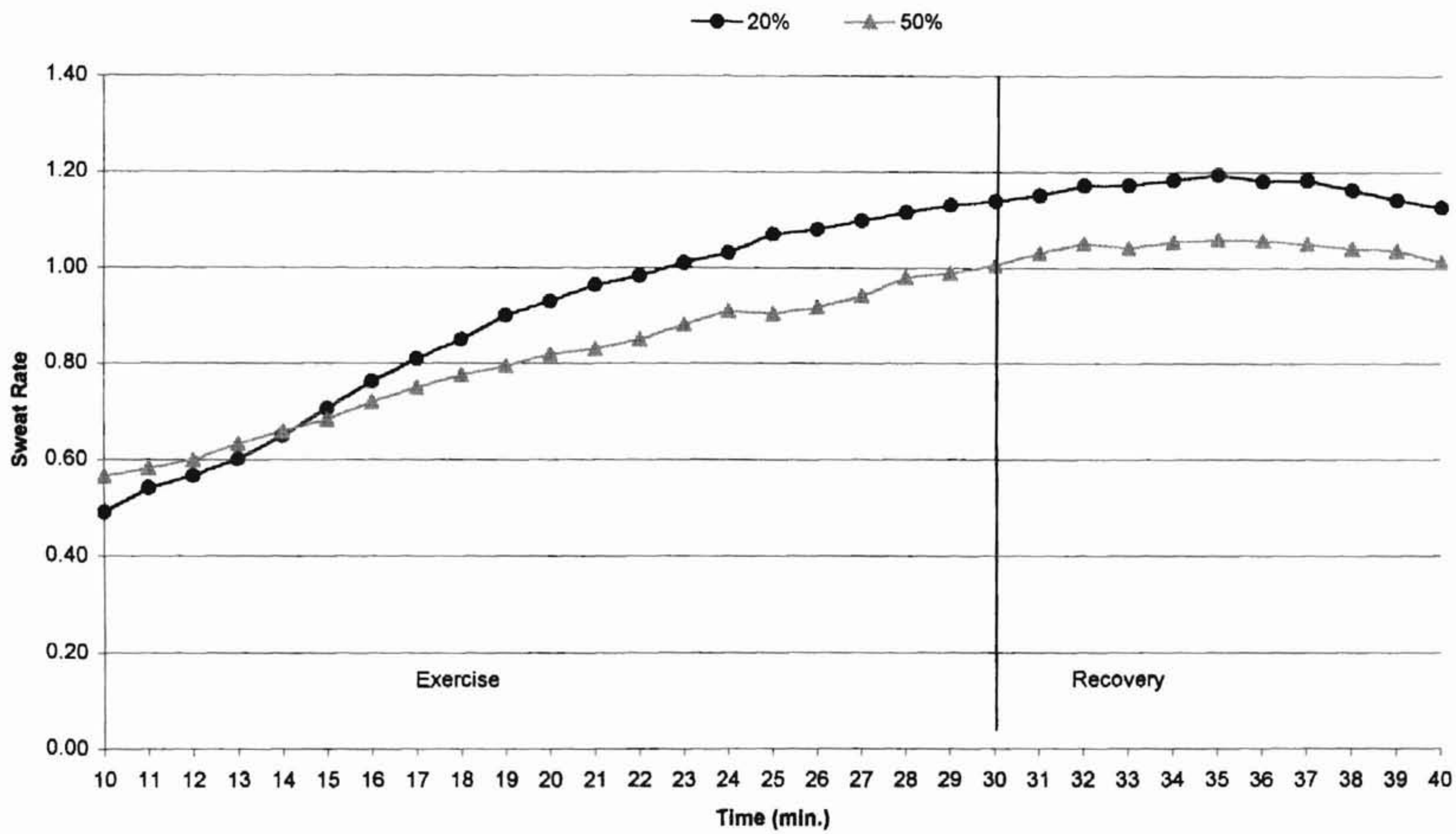

Figure 10: Leg Sweat Rate for environmental x time.

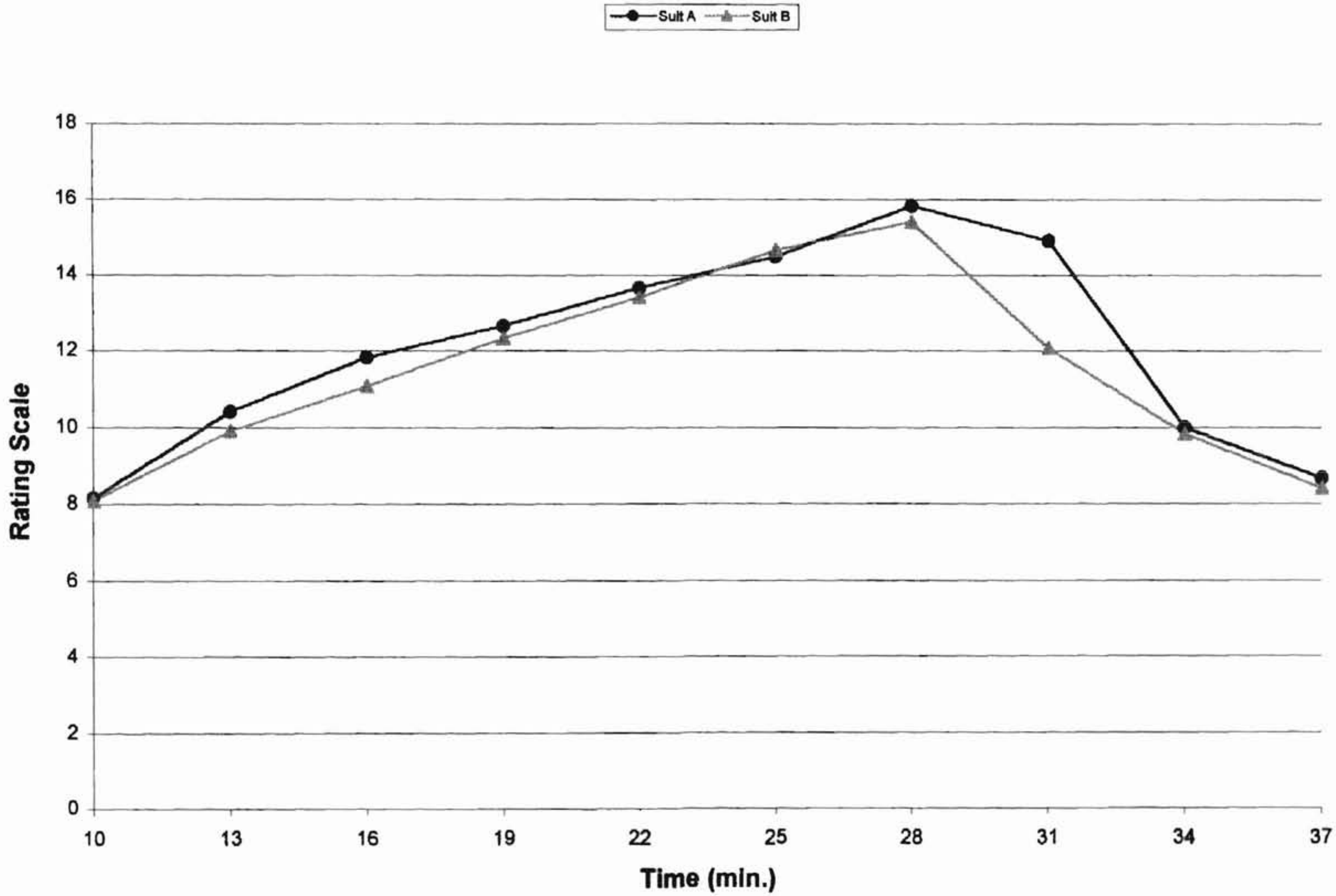

Figure 11: Mean Rate of Perceived Exertion for suit A and B over time.

Table 7 Overall Means of Comfort Evaluations by Suit Treatment Over Time

		Rating Periods					
Descriptor	Suit	10	15	20	25	30	35
Absorbent **	A	0.5	0.83	1.33	1.17	0.83	1.42
	B	1.25	1.67	1.25	1.08	0.92	1.42
Breathable*	A	1.17	0.83	0.92	0.75	0.75	1.83
	B	2.08	1.58	1.17	1.08	0.92	2.25
Clammy*	A	0	0.83	1.33	1.5	1.83	1.58
	B	0.25	1	1.83	2.33	2.58	2.25
Clingy*	A	0.67	1.33	1.92	2.42	2.33	2.17
	B	0.67	1.25	1.92	2.33	2.42	1.83
Comfort*	A	2.08	1.5	1.25	1.17	1.17	2.42
	B	2.33	2.17	1.58	1.33	1.42	2.33
Constrictive**	A	2.42	1.83	1.92	2	2.5	1.08
	B	1.5	1.5	1.92	2.08	2.5	1.25
Damp*	A	0.42	1.17	2	2.42	3.08	3.17
	B	0.17	1.25	2.5	3.08	3.5	3.17
Dry**	A	2.75	1.83	1.33	0.75	0.58	0.42
	B	3.67	1.75	0.92	0.25	0.08	0.42
Flexible*	A	2.25	2.17	2	1.58	1.33	2.42
	B	2.75	2.33	1.75	1.58	1.5	2.75
Heavy*	A	1.75	2	2.5	2.58	2.83	1.67
	B	1.58	1.67	2	2.33	2.42	1.5
Hot*	A	1.5	2.33	2.75	3.17	3.33	2.67
	B	0.83	1.58	2.33	3.08	3.5	2.42
Snug*	A	2.33	2	2.17	2.58	2.58	1.42
	B	2.08	1.83	2.17	2.17	2.42	1.67
Stiff*	A	1.33	1.25	1.33	1.33	1.58	0.67
	B	0.92	1	1.33	1.5	1.42	1.08
Thick*	A	1.67	2.25	2.33	2.42	2.83	1.92
	B	1.83	2	2.42	2.42	2.5	1.75
Warm*	A	1.75	2.67	3.08	3.33	3.58	3
	B	1.67	2.33	3	3.83	3.92	3.08
Wet*	A	0.08	1	1.83	2.5	2.92	2.92
	B	0.08	1	1.92	2.92	3.08	3.08

* indicates $P < .05$ for Time

** indicates $P < .05$ for Suit x Time

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

Over the past twenty years, heat stress related heart attacks of active duty fire fighters continue to be the leading cause of fire fighter fatalities, accounting for approximately half of the deaths. The term on duty applies to all personnel active at the scene of an emergency, whether it is a fire or non-fire related incident. The fatalities that are reported occur on the fire ground, while in training, while going to or returning from an emergency, or while performing other duties that support fire service operations.

In 1997 ninety-four fire fighters died while on duty. Figure 1(p.1) shows the distribution of the 94 deaths by the medical nature of the fatal injury or illness. The leading cause of these deaths was heart attacks, which accounted for 36 deaths in 1997. Many of the heart attack fatalities were individuals who had previous heart problems.

Researchers have suggested that although the fire gear has played a role in reducing the percent of deaths and injuries from burns, it also may have exacerbated a problem that continues to plague fire fighters, namely heat stress (Bone et.al, 1994). Typically, physical work in a hot environment results in a core temperature rise of 1° C to 1.5°C. In addition to the heat inherent to the fire fighting environment, the weight and stiffness of the personal protective equipment (PPE) that fire fighters wear imposes additional physical strain on the wearer, which causes an increase in the workload. An increased work load will also shorten the time it takes a fire fighter to become fatigued, reducing the amount of time one can actually work in a hot environment.

The purpose of this investigation was to compare the physiological and perceptual responses of subjects wearing two types of turnout gear while performing a typical fire fighting workload in controlled environmental conditions. Student fire fighters participated in a protocol that simulated moderate fire fighting work activity in two environmental climates.

A review of literature revealed that numerous studies have addressed reduction of the thermal stress by using various combinations of materials and components. Yet, the weight of the ensemble has not been addressed as a major issue. Therefore, the objectives of this study were to 1) compare subjects' perceptual responses including rate of perceived exertion, thermal comfort, moisture, and an overall comfort rating while wearing the two test turnout ensembles, under two environmental conditions, and over time and, 2) compare subjects' physiological responses including skin temperature, tympanic (Tty) temperature, sweat rate, and heart rate, while wearing the test turnout ensembles, under two environmental conditions, and over time. Null hypotheses were developed for each objective.

Testing Protocol

Testing took place in a controlled environmental chamber in two different environmental conditions. Each subject wore both turnout ensembles in both environments for a total of 4 test periods. The conditions were limited to the following two environmental conditions, 22.2° ± 2°C and 50%±5% RH, and 22.2° ± 2°C and 20%±5% RH.

For the purpose of this study, the following variables were controlled: age between 20-23, gender, physical condition, physical activity, exposure time, and similar height and weight. Each subject wore the same components, station uniform, gloves, hood, and self-contained breathing apparatus, in addition to the test garments. Subjects wore their own undergarments, socks and boots. The boots were rubber boots which all met NFPA specifications. The station uniform consisted of pants and long sleeved shirts made of 100% Nomex twill. Gloves and hood were provided to each subject. All components met or exceeded the NFPA standards.

The independent variables in this study included two variations of turnout gear and two environmental conditions. Ensemble "A" was typical of structural fire fighting gear that met minimal NFPA 1971 standard. Ensemble "B" was a newer, lighter weight structural fire fighter gear. Table 6 (p 35) provides the specific components of each ensemble and Figure 2 and 3 (p 36-37) shows the design features of the test ensembles.

The dependent variables included subjects' core temperature, weighted skin temperature and three local skin temperatures, sweat rate at two locations, heart rate, rate of perceived exertion, and the effective measures of thermal sensation, comfort, and moisture.

Core temperature was measured by a QuestempII datalogging personal heat stress monitor using a tympanic ear probe. Skin temperature was measured with skin thermocouples, located on specific sites at the chest, arm, and leg (Appendix H). Mean skin temperature was computed using the formula given in Rohles, Milliken, and Krstic.[12]

Two dew point capsules located on the chest and leg were used to collect dew point (Appendix H). Heart rate was recorded every minute using a Polar Accurex II heart rate monitor. Subjects wore the transmitter around their chest and the monitor on their wrist. Skin temperature, sweat rate, core temperature, and heart rate were recorded at 1-minute intervals and downloaded into a computer for observation.

A comfort ballot developed by Hyun, Hollies, and Spivak, [13] was modified to include 16 descriptors including descriptors related to fire fighters' clothing (Appendix F). Subjects were asked to verbally rate their perception for each descriptor by responding to a 5-point intensity scale. Comfort ballots were administered immediately upon donning the gear and at five-minute intervals throughout each session. The Borg rate of perceived exertion (RPE) scale, (Appendix G) was administered every three minutes, primarily as a safety measure. This was analyzed to determine if the subjects' perception of increased exercise followed the actual increase in the exercise protocol.

The testing protocol consisted of four stages: preparation, acclimation, exercise, and recovery. The first stage, preparation, lasted 15 minutes and took place in the laboratory. The subject sat for fifteen minutes to allow his heart rate to become stable. A sample comfort ballot was completed during this stage. The subject then was instrumented with the heart rate monitor, dressed in the station pants and T-shirt.

Immediately upon entering the environmental chamber, the second stage, acclimation began. This stage lasted 15 minutes. The subjects, dressed in their station pants and T-shirt, were instrumented with the skin temperature thermocouples and sweat rate capsules. Skin temperature was taken at the chest, lower arm, and lower leg. Sweat rate capsules were located on the chest and arm. After instrumentation the subject was allowed to put on the shirt and hood. A tympanic ear probe was placed in each subject's ear and calibrated, using an oral thermometer. This took approximately 8-10 minutes. The turnout pants, boots, jacket, helmet, SCBA and facemask were donned. The first comfort ballot was administrated before the subject hooked up the air hose. Upon completion of the ballot, the subject hooked up the air tank and put on his gloves, then a RPE ballot was administrated.

The third stage, exercise, lasted 20 minutes. The subjects walked on a treadmill beginning at 3.3 mph and 0% grade. At 5-minute intervals, the grade was increased 3%. This physical activity was sufficient to induce sweating. Response to RPE ballots were completed every three minutes and the comfort ballot every five minutes. Subjects were asked to assess their perception of the intensity they experienced related to each descriptor. The investigator completed each ballot as directed by the subject.

Stage four, recovery, lasted approximately ten minutes. The investigator slowed the treadmill to 2.2 mph with a 0% grade, and the subjects continued to walk for ten minutes. Both the RPE and comfort ballots were completed during recovery. During the recovery, the subjects were instructed to remove their gloves to enable the investigator to read the heart rate monitor. At one-minute intervals, the subjects were allowed to begin removing their helmet, SCBA and turnout coat to aid in the recovery process. The subjects continued to walk on the treadmill until the ten minutes had ended.

At the end of the recovery stage, the subjects removed the rest of their gear, all thermocuples, and sweat capsules. The tympanic and heart rate monitor remained on the subject, and the subject and the investigator left the chamber. The subject sat quietly in a chair until his heart rate fell below 100 beats/minute. At this time the instrumentation was removed and the subject was allowed to change into his own clothing. Final questions were asked and water or Gatorade was given to the subjects. They were encouraged to continue to rest if needed. This protocol was followed for all test sessions.

Due to the strenuous task each subject was under, each subject was allowed to request early termination if any of the following criteria were present, the experiment was to terminate: 1) If the subjects' core body temperature rose above 38°C, 2) If the subject felt that he could not continue despite verbal encouragement, 3) If the subject's SCBA sounded a low-pressure alarm. There were several times the test could have been terminated, due to the low-pressure alarm and the subjects core temperature rising above38°C, but the subjects requested that they be allowed to continue the test session. Each subject was closely monitored for changes in behavior. All subjects completed each test session.

Conclusions

<u>Physiological Data</u>. In looking at the skin temperature at the chest, leg, and arm locations the same pattern existed, namely suit A begans with a lower skin temperature, and by the end of the test the skin temperature at all locations were higher than suit B. An ANOVA found this difference to be significant at the $p<.05$ level. The weighted mean skin temperature followed the same pattern, with suit A beginning with a lower weighted mean skin temperature, and rising throughout the exercise session. During the recovery period the temperature in suit A continued to rise before dropping.

When comparing skin temperature to core temperature, suit A showed a higher core temperature. This would suggest that suit A did not allow the heat within the body to escape into the environment. When comparing skin temperature and core temperature in suit B, the heat from within the body reached the surface of the skin allowing it to dissipate into the environment allowing the subject to have a lower core temperature. Although, there was a definite trend for subjects in suit A to experience a higher core temperature than subjects in suit B. It should be noted that with a larger sample this observed trend might be significant.

Skin temperature and core temperature were compared with heart rate data a pattern emerged that correlates with heart rate. Suit B began with a lower heart rate and remained lower throughout the test period. During the recovery period suit B had a higher heart rate but dropped very quickly to became even with suit A by the end of the test session. Research has indicated that the heart rate will continue to rise for a period of time after the work has ended.

In looking at sweat rate at the two locations (chest, leg), subjects wearing suit B showed a higher rate of sweat than subjects wearing suit A. Again, this followed the same pattern as skin temperature, and core temperature with the notion that a lighter weight suit allowed for the heat from the core to rise to the surface and to be dissipated into the environment.

<u>Perceptual Data.</u> Results of analysis of variance for perceived comfort indicated a significant garment effect for three of the 16 comfort ballot descriptors: absorbent, constrictive, and dry. For the descriptors constrictive and absorbent, suit B was more absorbent, and less constrictive at the beginning, but as the session progressed it was

difficult to determine which suit was perceived as more absorbent or less constrictive. Garment A was also rated the driest of the two suit treatments.

There was a significant time effect for 13 of the comfort descriptors: breathable, clingy, clammy, comfort, damp, flexible, heavy, hot, snug, stiff, thick, warm, and wet. For the descriptors snug and stiff, there was a slight change in the intensity over the course of the exercise. There was an increase in the intensity of perceived damp, clammy, clingy, hot, wet, and warm regardless of the suit treatment. This may be explained by the moderate to heavy sweating of the subjects that occurred over the course of the exercise protocol. A slight increase in the intensity of the perceived descriptors flexible, thick, and heavy was observed, and a slight decrease in perceived comfort and breathable for the two suits. This was most likely due to the amount of stress the full turnout gear places on the fire fighters.

There was a significant time effect for the rate of perceived exertion. The intensity level increased throughout the test session and began to decrease during the recovery. This was most likely due to reducing the grade and rate of speed on the treadmill. This was a very typical response to the exercise protocol.

Recommendations for Future Research

The following recommendations for further research were stated:

1. It is recommended that future research that could focus on one factor at a time would be helpful to be able to pinpoint the reason for the observed differences.

2. It is recommended that increasing the sample size and repeating the test protocol might show more significant differences between the two suits.

3. Repeating the same protocol, but increasing the time of the exercise session. For example, exercise, recovery, then repeating the exercise protocol.

4. Incorporate exercise that would also use the upper body as well as walking on the treadmill to simulate the typical work produced by the fire fighter. For example, if you simulate shoveling how would it make a difference in the outcome.

5. To examine if gender differences would be present. For example, repeat test but use females and compare their physiological or perceptual data to this study, in order to determine any significant differences.

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APPENDICES

APPENDIX A

SUBJECTS ADVERTISEMENT

Earn $100.00

Do you fit these qualifications?

- Age: 20-35
- Good physical condition
- Fire Protection Student

Then the Department of Design, Housing & Merchandising is

Looking for YOU

- DHM is conducting research which will involve wearing the full fire gear and walking on a treadmill in an environmental chamber under two different environmental conditions.
- Subjects will be expected to participate in four test sessions, plus a prescreening test.
- Test sessions will be conducted in September

If interested contact Diane at 744-5035 or 372-6235 (between the hours of 5-10pm)

APPENDIX B

INFORM CONSENT

INFORMED CONSENT

I, ______________________________, voluntarily agree to participate in this study entitled: A Comparative Analysis of Heat Stress Associated with Selected Turnout Gear Ensembles which is sponsored by College of Human Environmental Sciences through the Department of Design, Housing, and Merchandising, Oklahoma State University, Stillwater, OK.

I understand that the purpose of this study is to compare the physiological and perceptual responses of subjects wearing two types of turnout gear, and that testing will involve an exercise program to be completed at Oklahoma State University in the department of Design, Housing, and Merchandising's Environmental Chamber with each of these turnout gear ensembles.

I understand the procedures for comparing physiological and perceptual responses will require my participation in the following ways.

1. **Pre-Test:** You will participate in a fit test to determine if you fit the test gear. After passing the fit test, a physical screening to determine you fitness level will take place. You will be asked to complete a PAR-Q test, which identifies if the planned physical activity is appropriate for you. After the PAR-Q, you will go to the Wellness Center, fill out a medical history analysis, and have lab tests to determine your blood pressure, cholesterol, and percent of body fat. A staff member of the Wellness Center will review your results. Lastly, you will be requested to perform a walk test to determine your maximal heart rate, predicted VO_{2max}, and fitness rating. From this, a homogenous group will then be selected as subjects.

2. **Testing**: The test is broken into four stages:

   Stage one: Preparation, will last 15 minutes. During this time the ensembles will be placed in a plastic bag and weighed. The subjects will sit for seven minutes to allow their heart rate to become stable. The subjects will then dress in the station uniform and sit quietly until the time is over. A sample comfort ballot will be filled out during this stage.

   Stage Two: During the15 minute acclimation period, subjects dressed in their station uniform, will be instrumented with skin temperature thermocouples, sweat rate capsules, tympanic ear probe, and heart rate monitor. Then the turnout gear, hoods, gloves and boots will be donned. After being instrumented, the subjects will be asked to verbally rate the intensity of a comfort sensation by responding: 0) not at all, 1) partially, 2) mildly, 3) definitely, and 4) totally.

Stage Three: Includes a 20-minute exercise protocol, which consists of walking on a treadmill at a rate of 3.3mph and a 0% grade. The grade will increase 3% every five minutes. Core temperature, skin temperature and sweat rate will be collected every minute. The rate of perceived exertion (RPE) ballot will be completed every three minutes and comfort ballots every five minutes. The subject may terminate the test if he feels he cannot continue. Heart rate, tympanic temperature, skin temperature, and sweat rate will be collected every minute by computer. The administrator will terminate the test if a subjects' core temperature rises above 38 °C, or the low-pressure alarm sounds on the SCBA, or the subject requests termination.

Stage Four: The subjects will go through a 10-minute cool down or recovery period. Subjects will slow the treadmill to 2.2mph 0% grade for approximately six minutes or until the heart rate drops under 100. Subjects will be asked to verbally complete the final comfort and RPE ballots. At the end of the recovery stage, all thermistor, sweat capsules, ear probe, and heart monitor will be removed and subjects will leave the chamber. This entire exercise protocol will be completed on four separate occasions while wearing two different turnout gear under two environmental conditions.

3. **Post- Testing:** Water and Gatorade will be given to the subjects upon completion of the test session. Post weight of turnout gear will be taken immediately after the subjects remove the gear and place it into a plastic resealable bag.

I understand that participating in this study presents the following possible benefits to me:

a) Experience in a research study
a) Knowledge that your input helped improve fire fighters' turnout gear
b) Payment of $100.00

I understand that minimal risks are anticipated by the investigator for participants in this study and that records of this study will be kept confidential with respect to any written or verbal reports making it impossible to identify me individually. I understand that I can withdraw from this study at any time without negative consequences. Payment is contingent upon completion of all test sessions

I have read this informed consent document and understand its contents. I freely consent to participate in this study under the conditions described here. I understand that I will receive a copy of this signed consent form.

Date: ____________________ Time: ____________________(a.m./p.m.)

Signed: ____

Signature of Subject

Witness ____

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

Signed: ____

Project Director

or his/her authorized representative

I may contact the principle investigator, **Diane Morton,** at **(405) 372-6235** should I have any questions or wish further information regarding this research. I also may contact **Dr. Donna Branson** (the advisor of the principal investigator) at telephone number **(405) 744-5035.**

APPENDIX C

PAR-Q TEST

Name:______________________

Date:________________

Physical Activity Readiness Questionnaire

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

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

If a person answers yes to any question, vigorous exercise or exercise testing should be postponed. Medical clearance may be necessary.

Reference: PAR –Q Validation report. British Columbia Department of Health, June 1975 (Modified Version)

APPENDIX D

MEDICAL HISTORY

Name_______________

Date__________

Medical History Analysis

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

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

Exercise history with information on habitual level of activity: type of exercise, frequency, duration, and intensity.

____

____

____

____

APPENDIX E

IRB FORM

OKLAHOMA STATE UNIVERSITY
INSTITUTIONAL REVIEW BOARD
HUMAN SUBJECTS REVIEW

Date: 08-06-98 **IRB #: HE-99-004**

Proposal Title: A COMPARATIVE ANALYSIS OF HEAT STRESS ASSOCIATED WITH SELECTED TURNOUT GEAR ENSEMBLES

Principal Investigator(s): Donna H. Branson, Diane R. Morton

Reviewed and Processed as: Expedited

Approval Status Recommended by Reviewer(s): Approved

ALL APPROVALS MAY BE SUBJECT TO REVIEW BY FULL INSTITUTIONAL REVIEW BOARD AT NEXT MEETING, AS WELL AS ARE SUBJECT TO MONITORING AT ANY TIME DURING THE APPROVAL PERIOD.
APPROVAL STATUS PERIOD VALID FOR DATA COLLECTION FOR A ONE CALENDAR YEAR PERIOD AFTER WHICH A CONTINUATION OR RENEWAL REQUEST IS REQUIRED TO BE SUBMITTED FOR BOARD APPROVAL.
ANY MODIFICATIONS TO APPROVED PROJECT MUST ALSO BE SUBMITTED FOR APPROVAL.

Comments, Modifications/Conditions for Approval or Disapproval are as follows:

Signature: Thomas C. Collins

Interim Chair of Institutional Review Board
and Vice President for Research

Date: August 19, 1998

cc: Diane R. Morton

APPENDIX F

COMFORT BALLOT

Comfort Descriptor Rating Sheet

Date ______________

Subject ____________________

Environment M-H M-L Garment ____________________

During the walk, you will be asked to verbally rate the intensity of each comfort descriptor. **<u>All blanks must be filled out each period.</u>** The administrator will fill in your response into the appropriate box. If you perceive additional sensations due to wearing, notify the administrator of your sensation and the time period in which they were noticed.

Use this intensity scale: 0 (Not at all)
1 (Partially)
2 (Mildly)
3 (Definitely)
4 (Totally)

Comfort Descriptors	Rating Period 1	2	3	4	5	6
Absorbent						
Breathable						
Clammy						
Clingy						
Comfortable						
Confining						
Damp						
Dry						
Flexible						
Hot						
Heavy						
Snug						
Stiff						
Thick						
Warm						
Wet						

Comments on the locations that feel uncomfortable.

____
____
____
____
____
____

Additional sensations noted.____________________________
____
____
____
____
____
____

Adaptation of Hyun, S.O., Hollies, N.R.S. and Spivak, S. M. (1991). Skin Sensation Perceived in Apparel Wear Part: I Development of a New Perception Language. Journal of Textile Institute. pp.392,393.

Intensity Scale

0 (Not at all)

1 (Partially)

2 (Mildly)

3 (Definitely)

4 (Totally)

Comfort Descriptors

Absorbent
Breathable
Clammy
Clingy
Comfortable
Constricting
Damp
Dry
Flexible
Hot
Heavy
Snug
Stiff
Thick
Warm
Wet

APPENDIX G

RPE SCALE

Rate of Perceived Exertion

6	
7	Very, very light
8	
9	Very light
10	
11	Fairly light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Very, very hard
20	

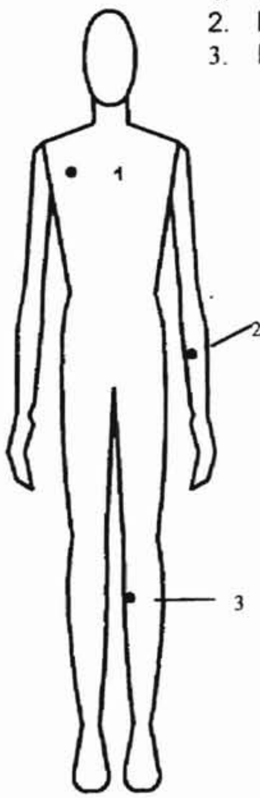
Reference: Borg,G. (1970). Perceived Exertion as an Indicator of Somatic Stress, Scandiavian Journal of Rehabilitation Medicine, (p.93).

APPENDIX H

SKIN TEMPERATURE AND SWEAT RATE SENSORS PLACEMENT

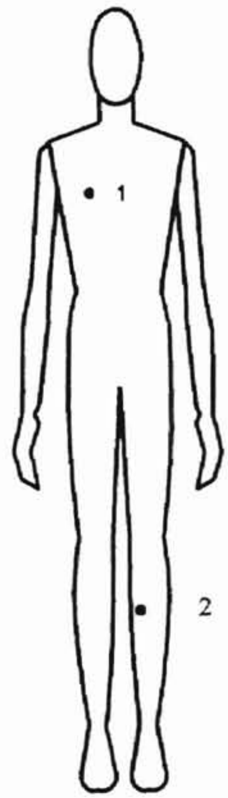
Skin Temperature Sensors

1. Chest
2. Lower Arm
3. Lower Leg



Sweat Rate Sensors

1. Chest
2. Lower Leg



Appendix I
GRAPHS OF VARIABLES

Figure 12: Mean Skin Temperature – Chest for both suits over time.

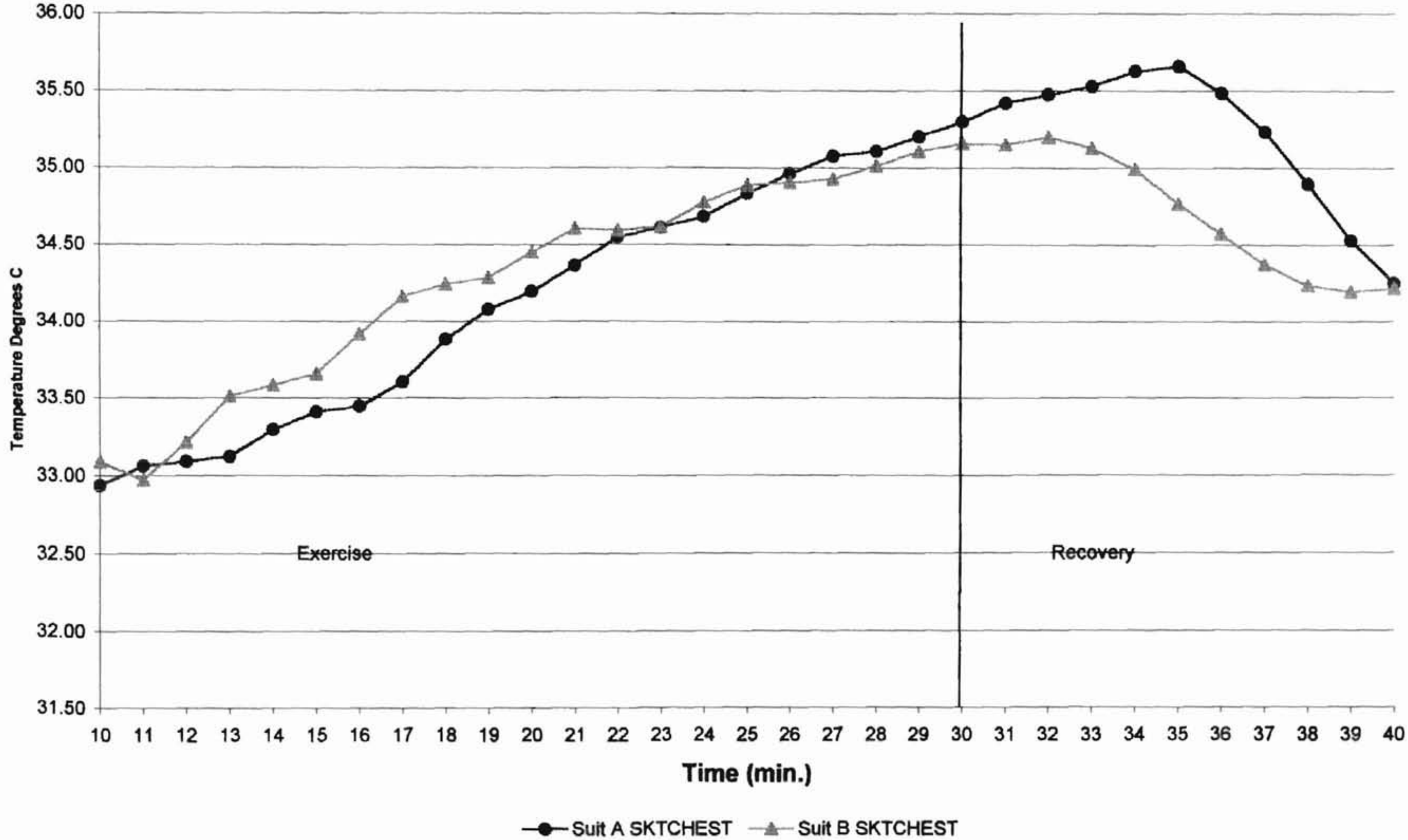


Figure 13: Mean Skin Temperature – Chest for suit A at 20% and 50% rh over time.

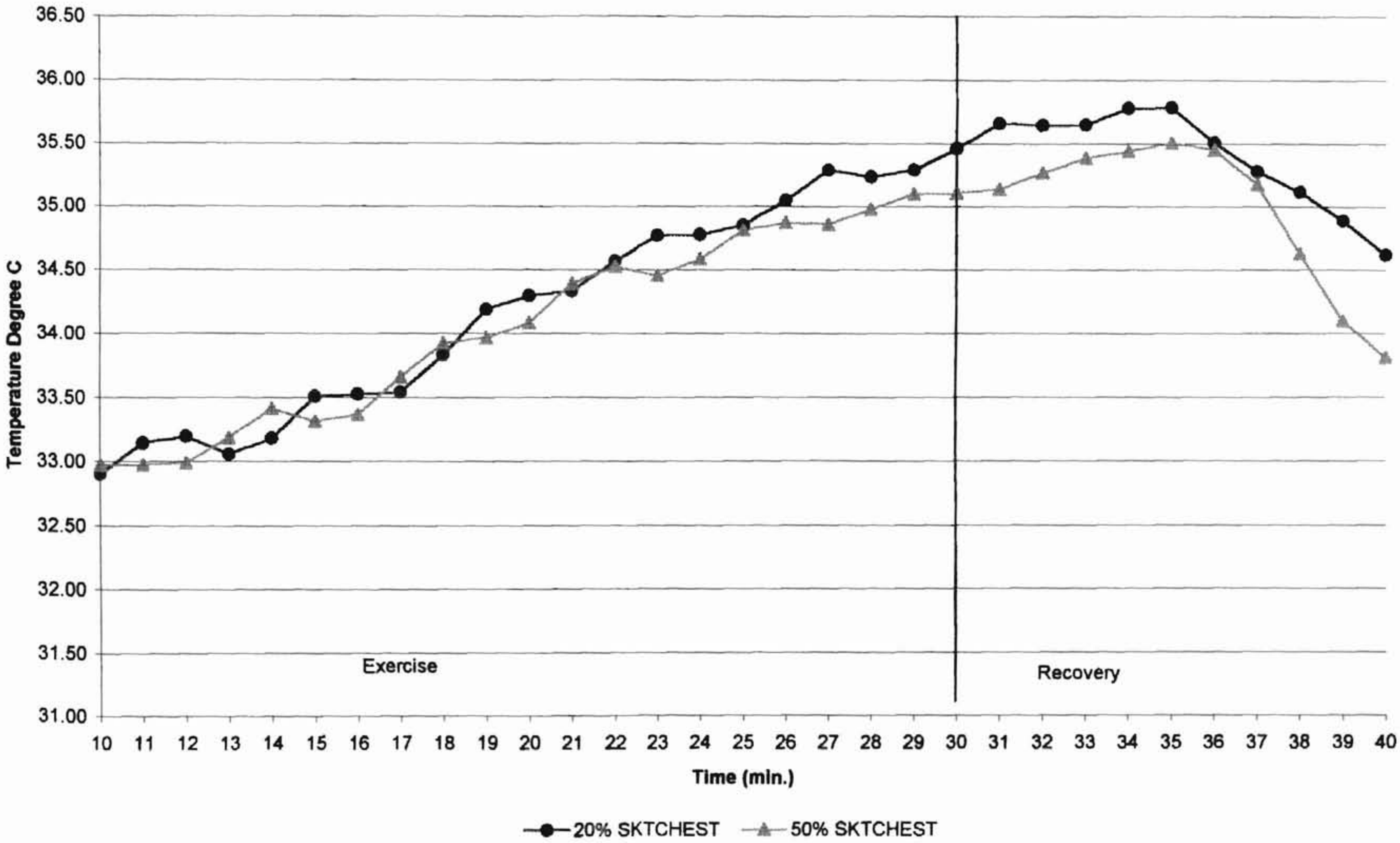


Figure 14: Mean Skin Temperature – Chest for suit B for 20 % and 50% rh over time.

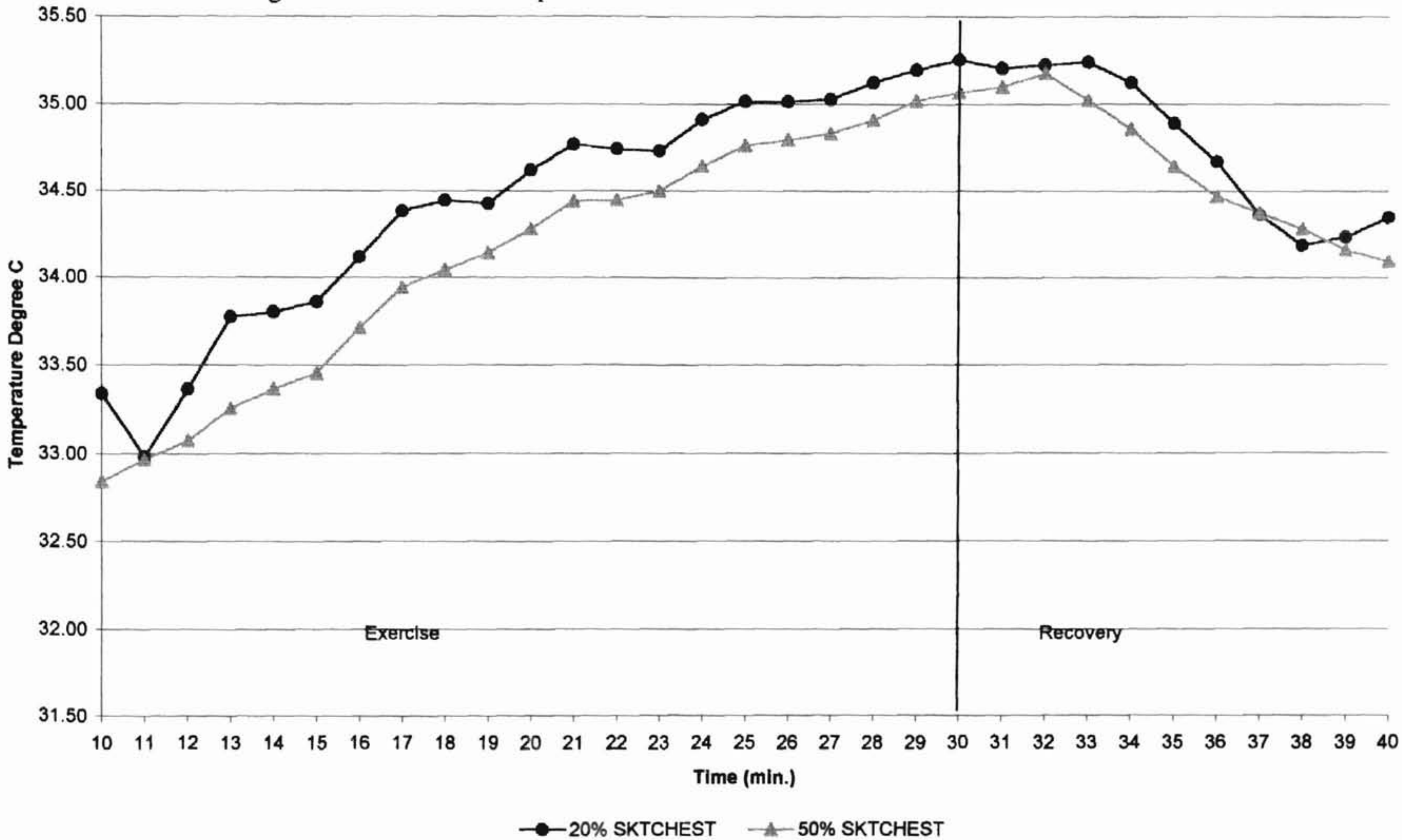


Figure 15: Mean Skin Temperature –Leg for both suits over time.

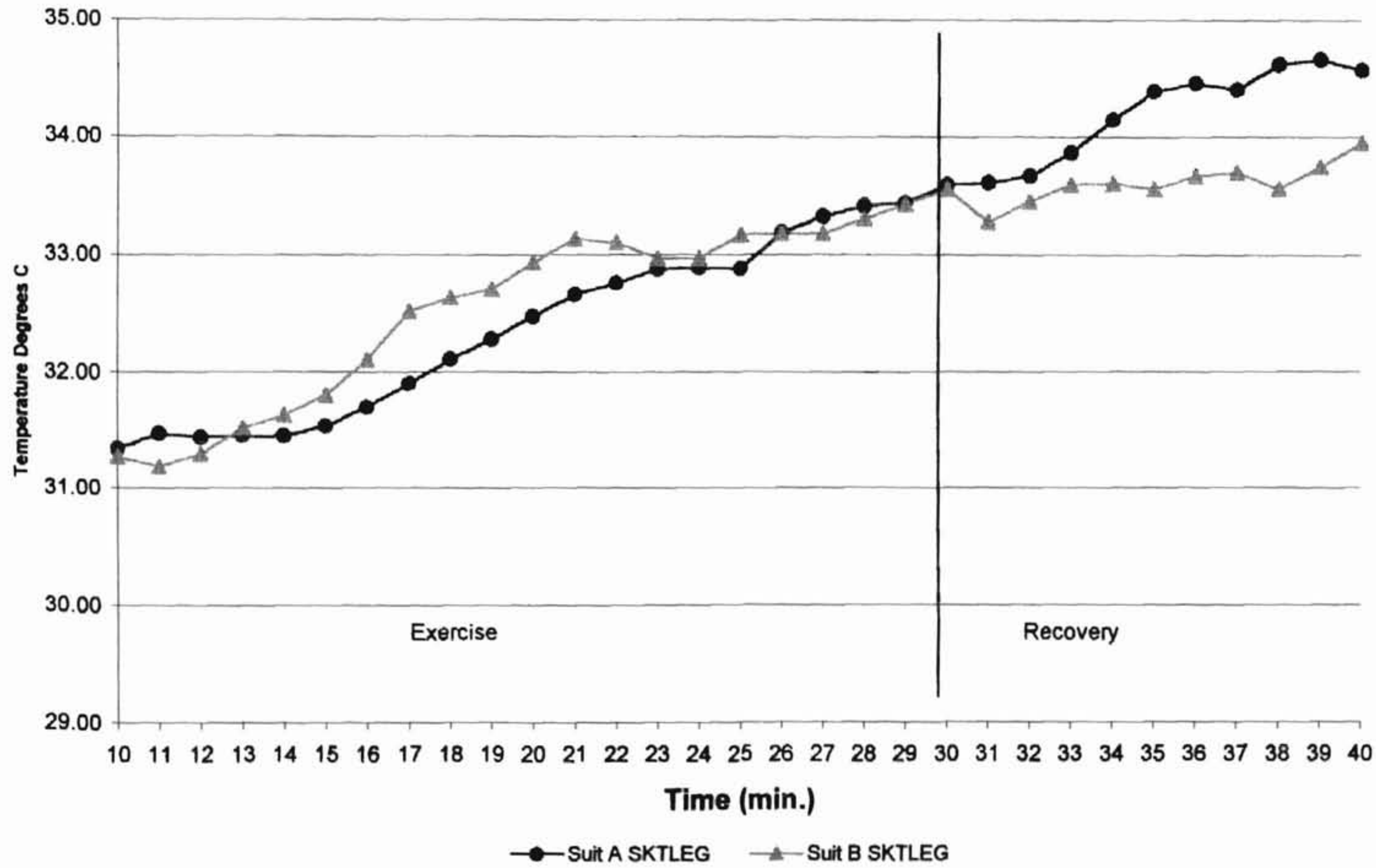


Figure 16: Mean Skin Temperature – Leg for suit A for 20% and 50% rh over time.

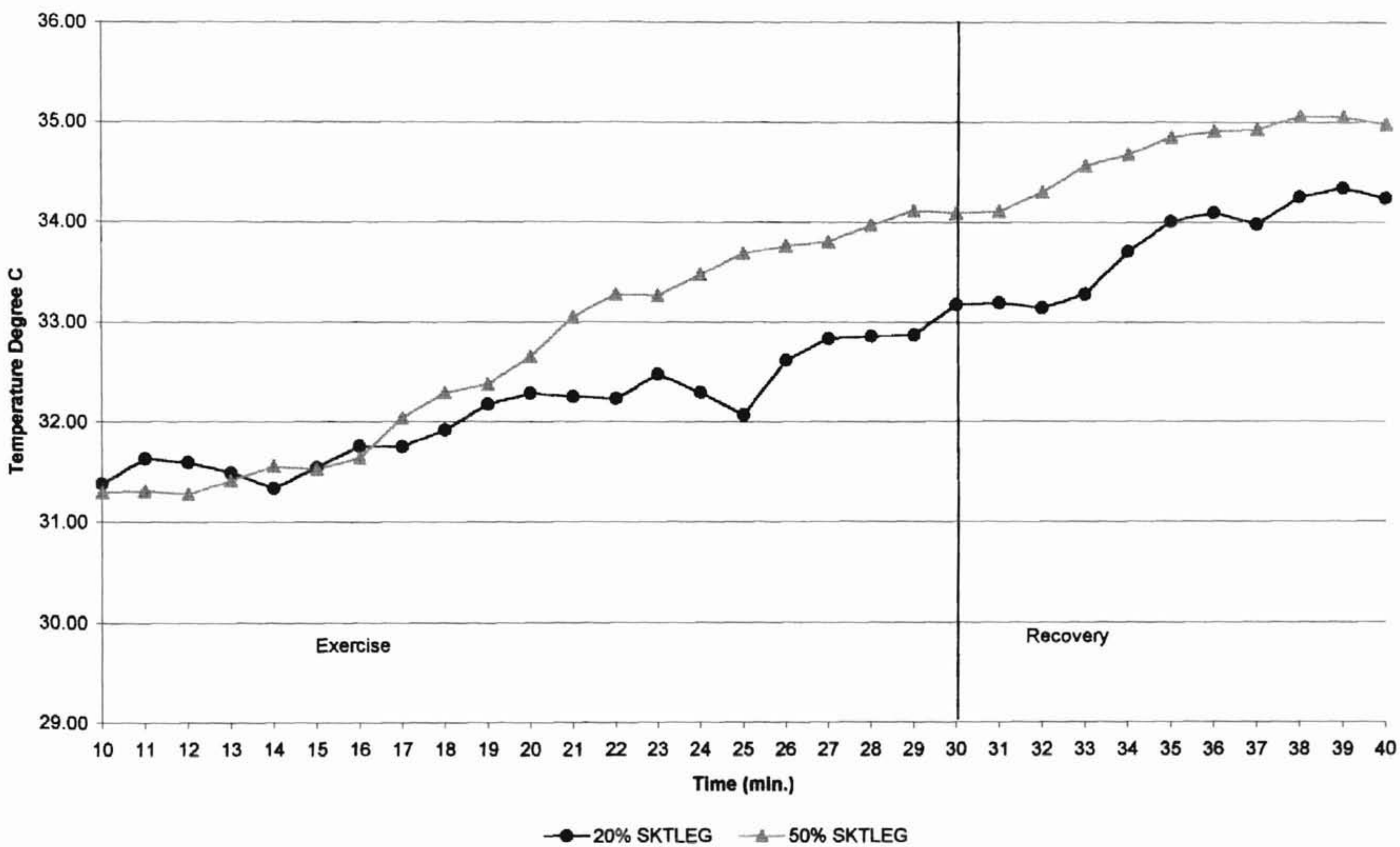


Figure 17: Mean Skin Temperature – Leg for suit B for 20% and 50% rh over time.

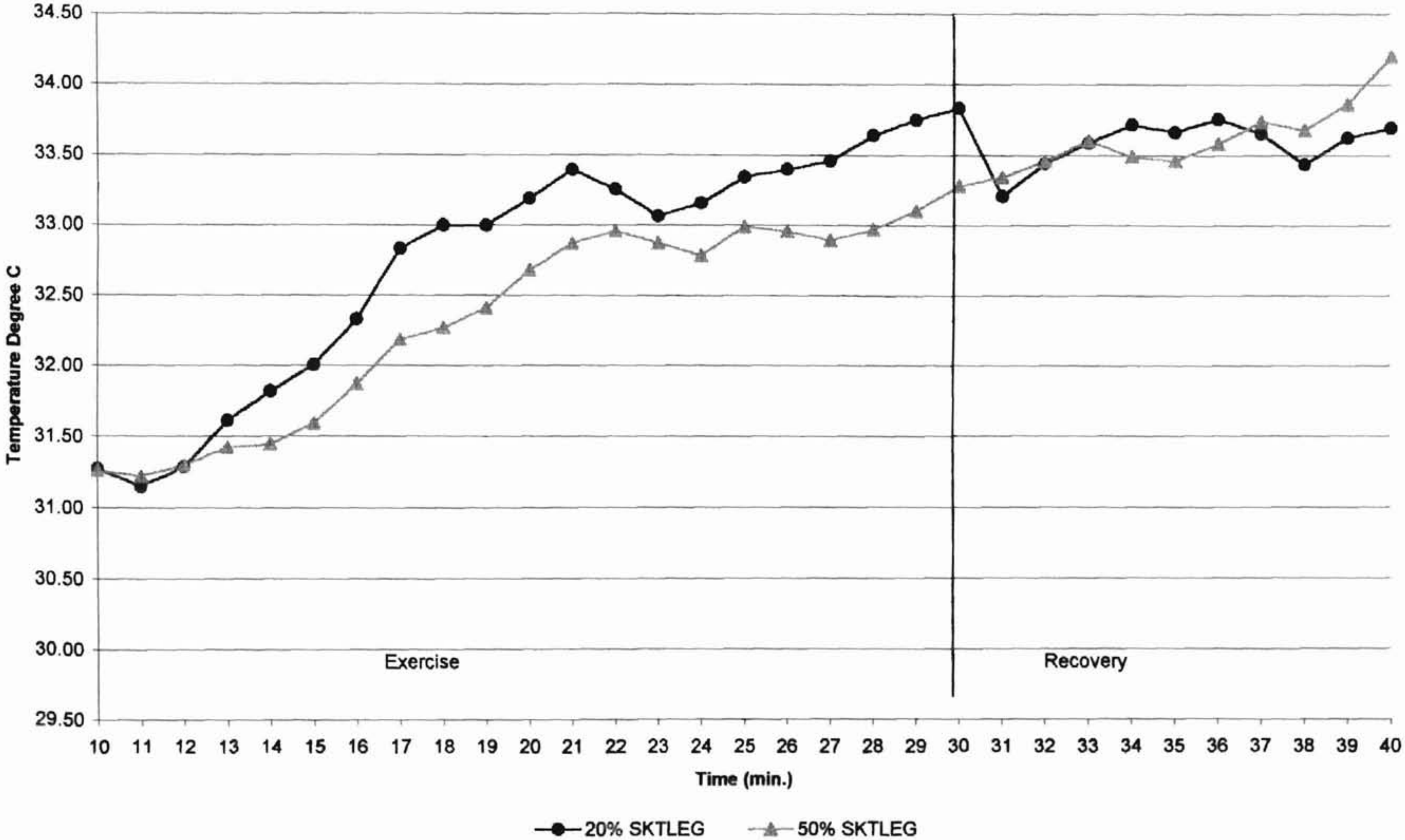


Figure 18: Mean Skin Temperature – Arm for both suits over time.

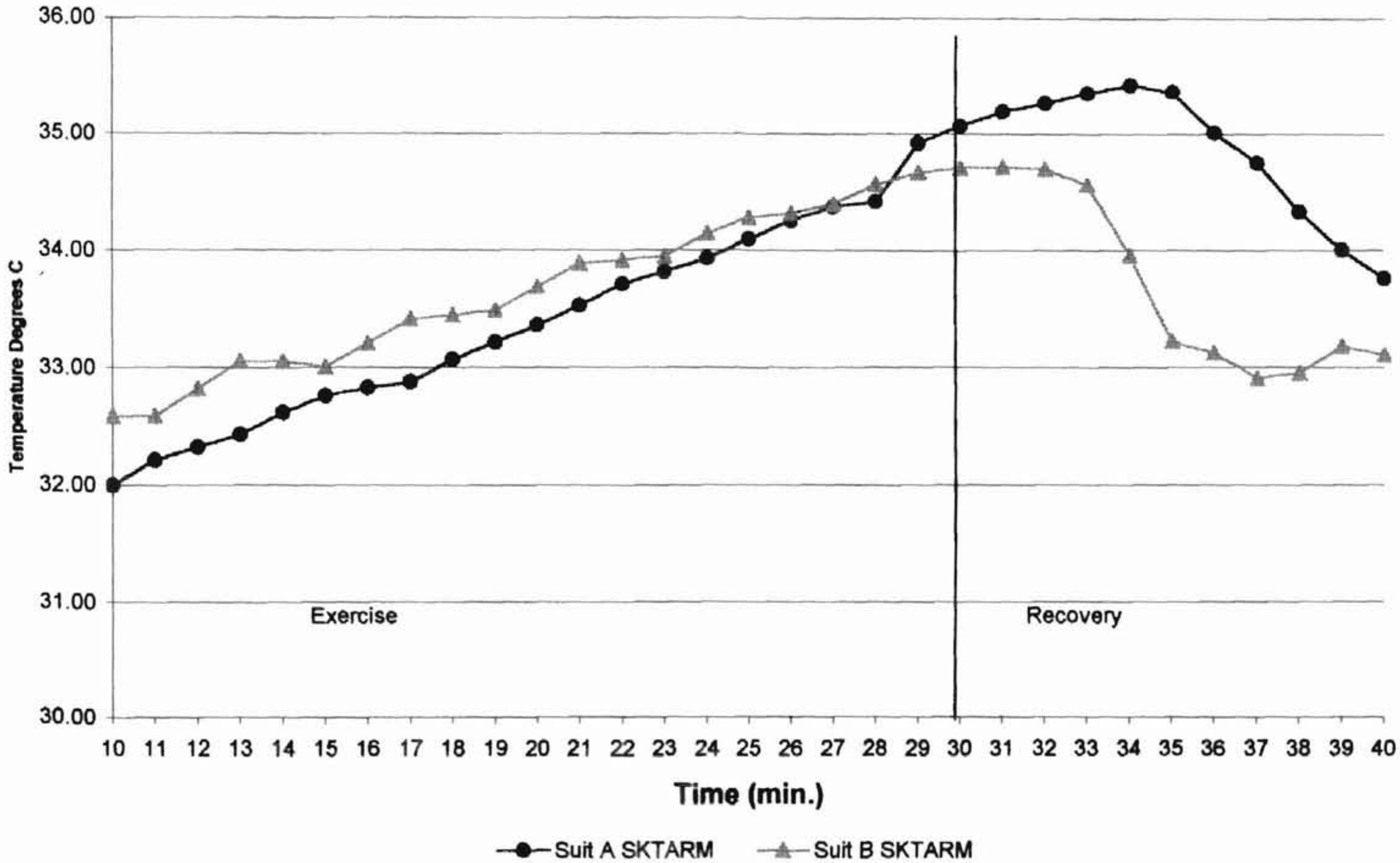


Figure 19: Mean Skin Temperature – Arm for suit A for 20% and 50% rh over time.

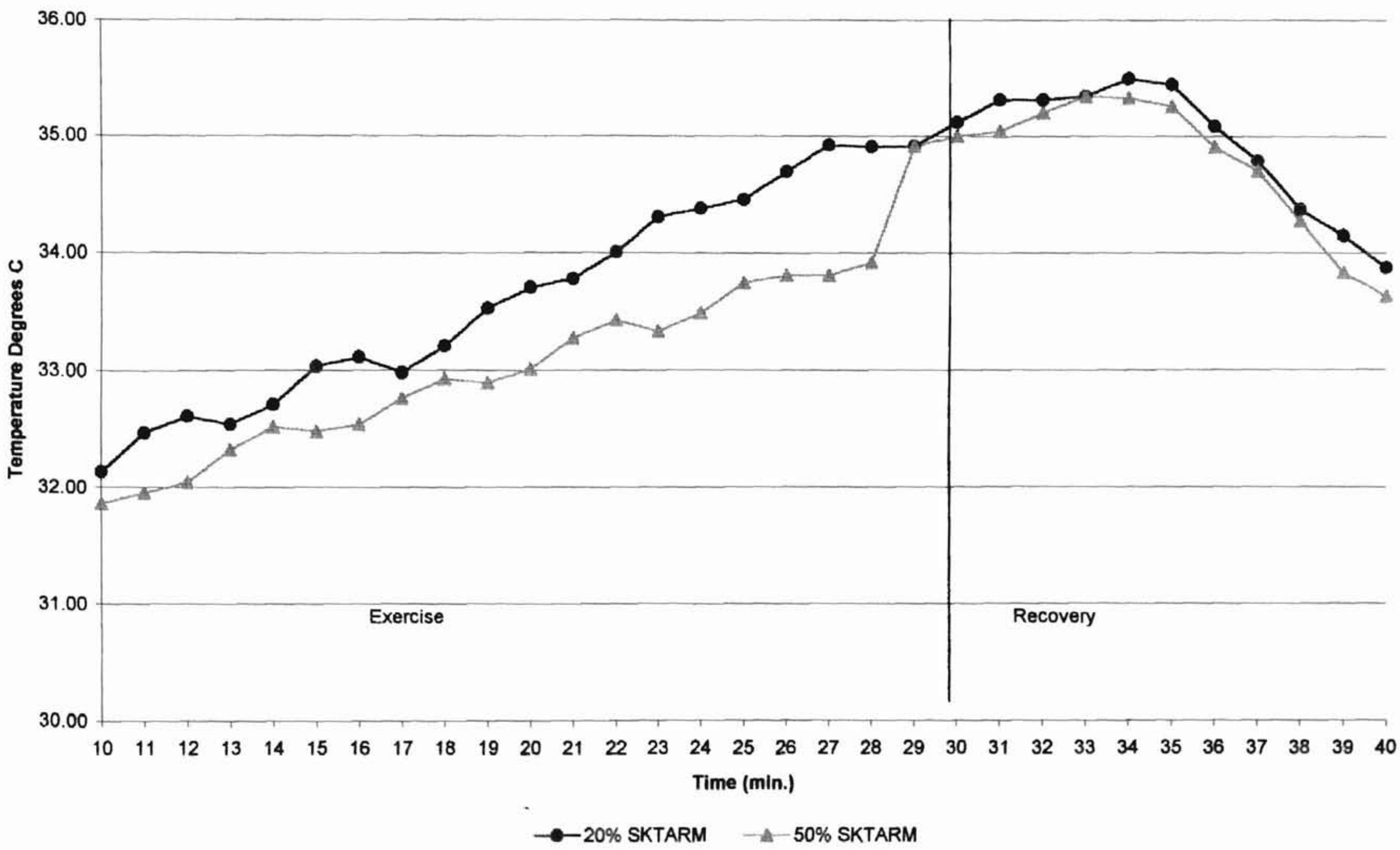


Figure 20: Mean Skin Temperature – Arm for suit B 20% and 50% rh over time.

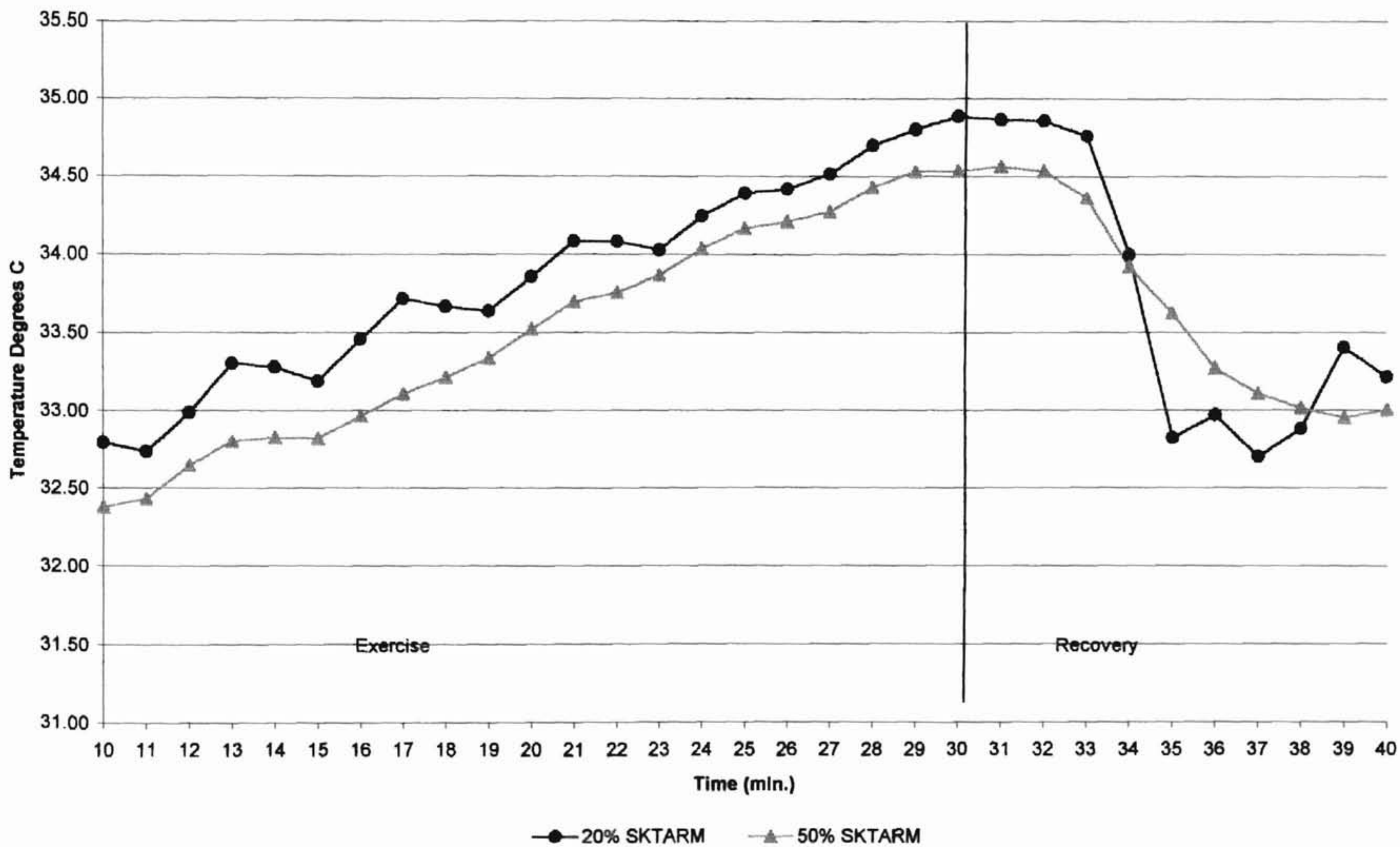


Figure 21: Mean Skin Temperature – Arm for Environment x Suit x Time

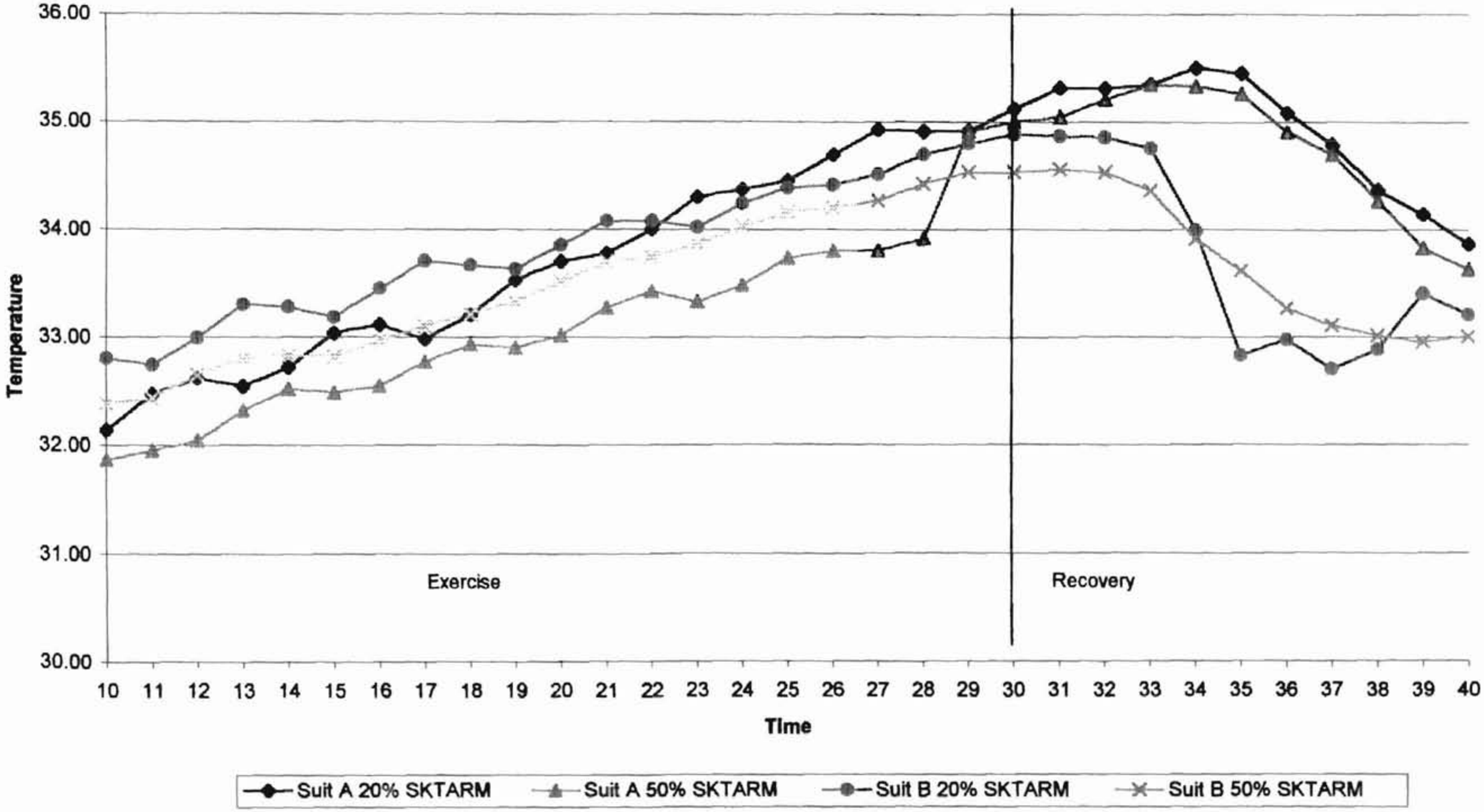


Figure 22: Mean Weighted Skin Temperature for suit A for 20% and 50% rh over time.

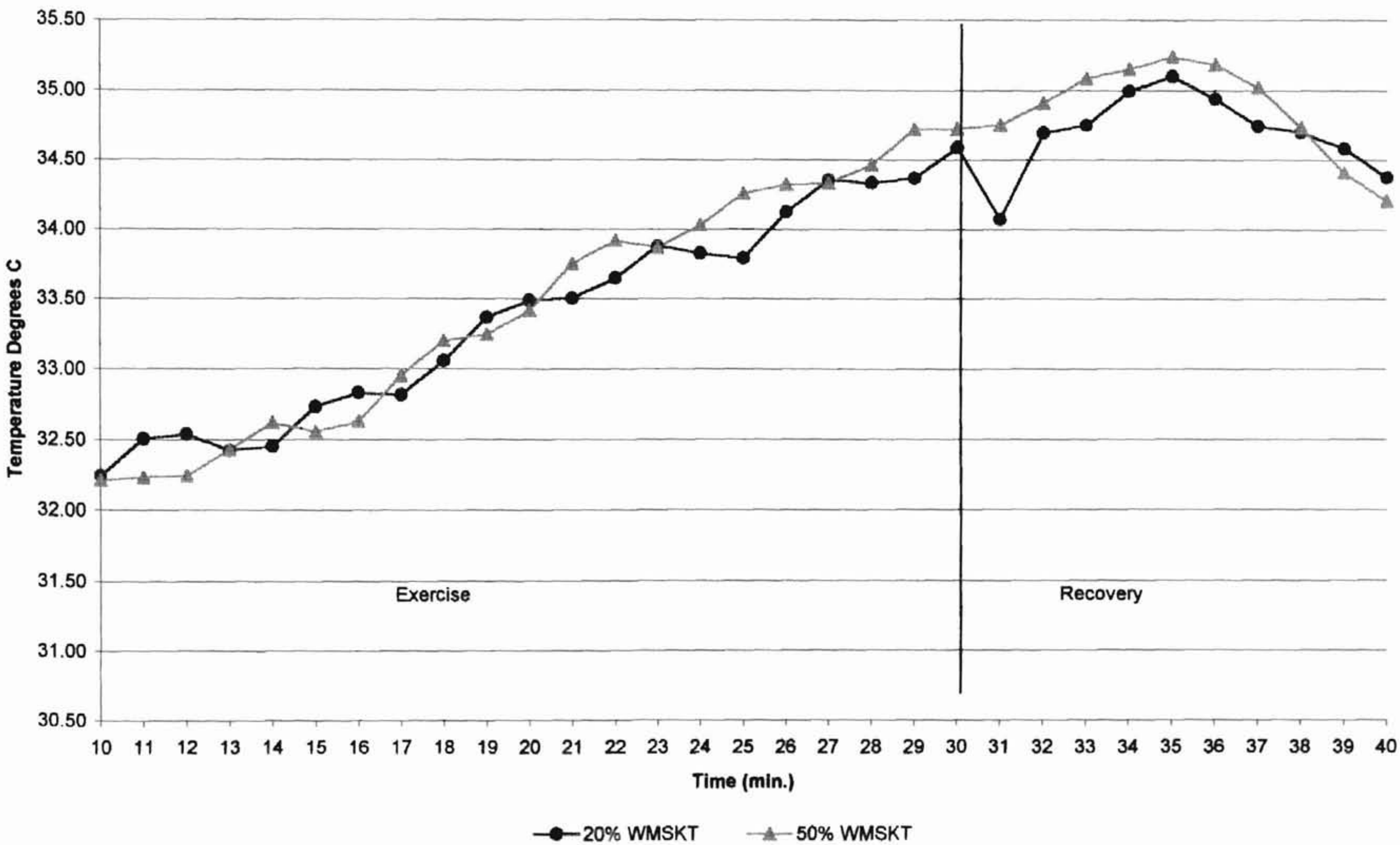


Figure 23: Mean Weighted Skin Temperature for suit B for 20% and 50% rh over time.

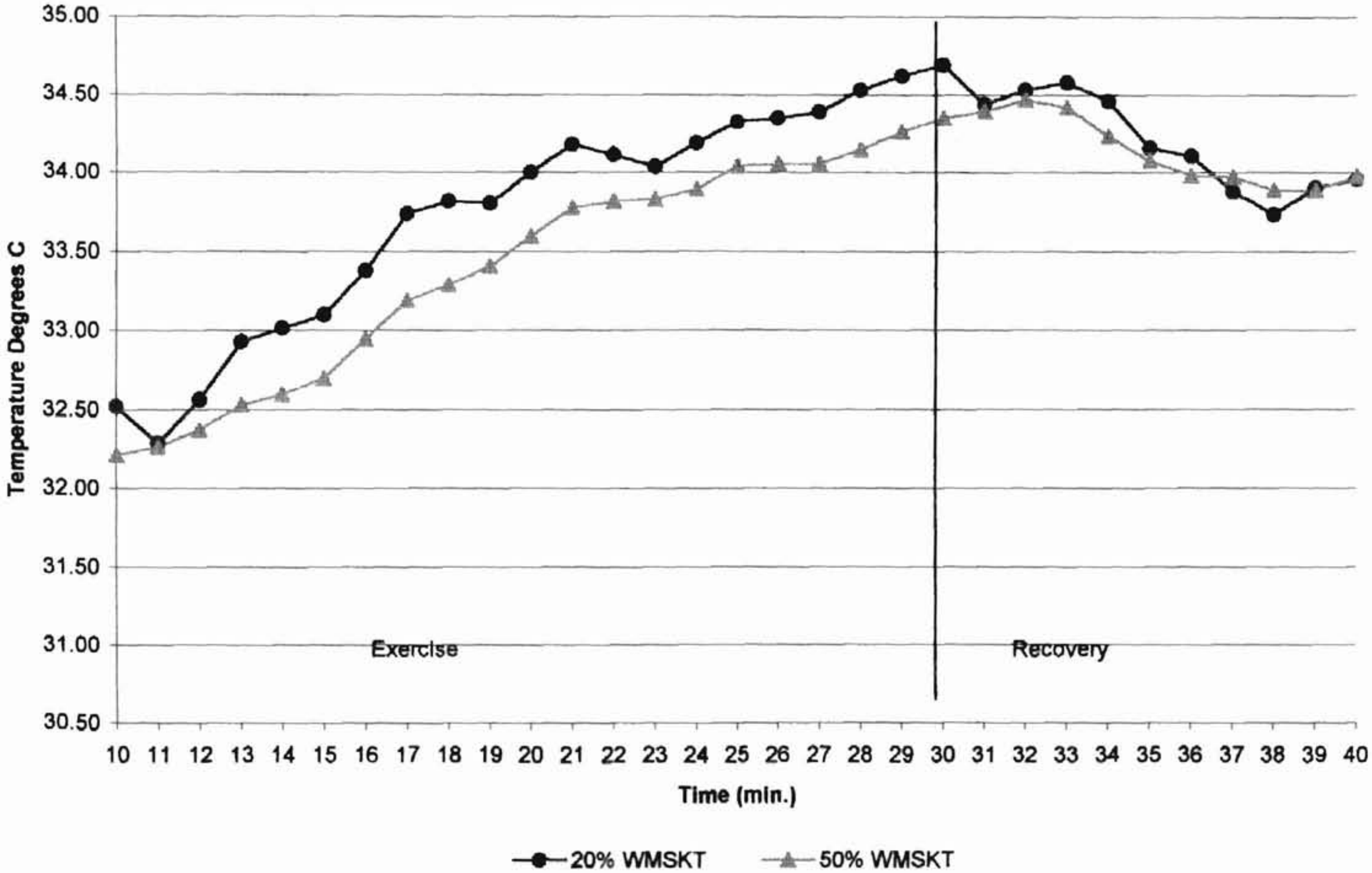


Figure 24: Mean Core Temperature for suit A for 20% and 50%rh over time.

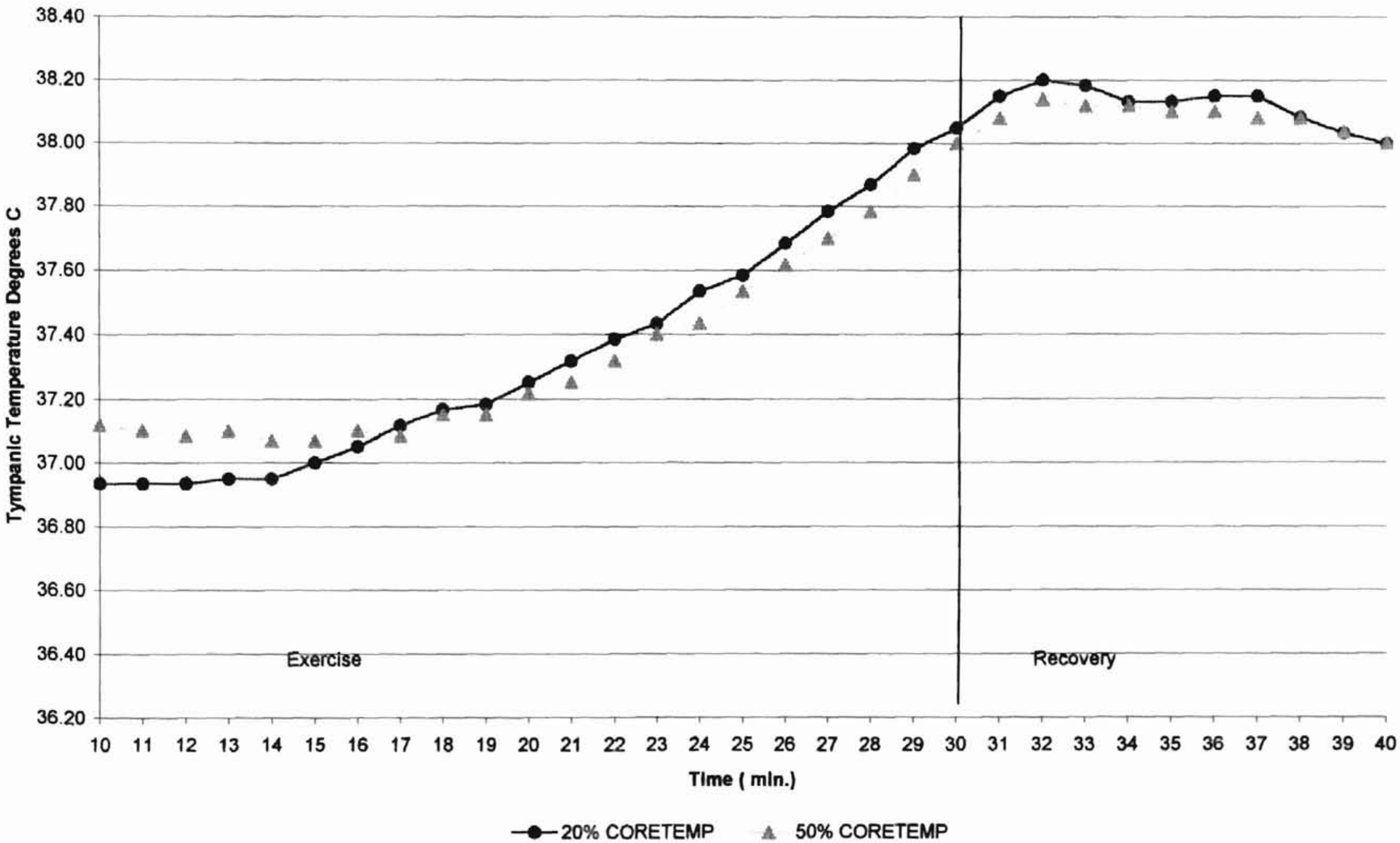


Figure 25: Mean Core Temperature for suit B for 20% and 50%rh over time.

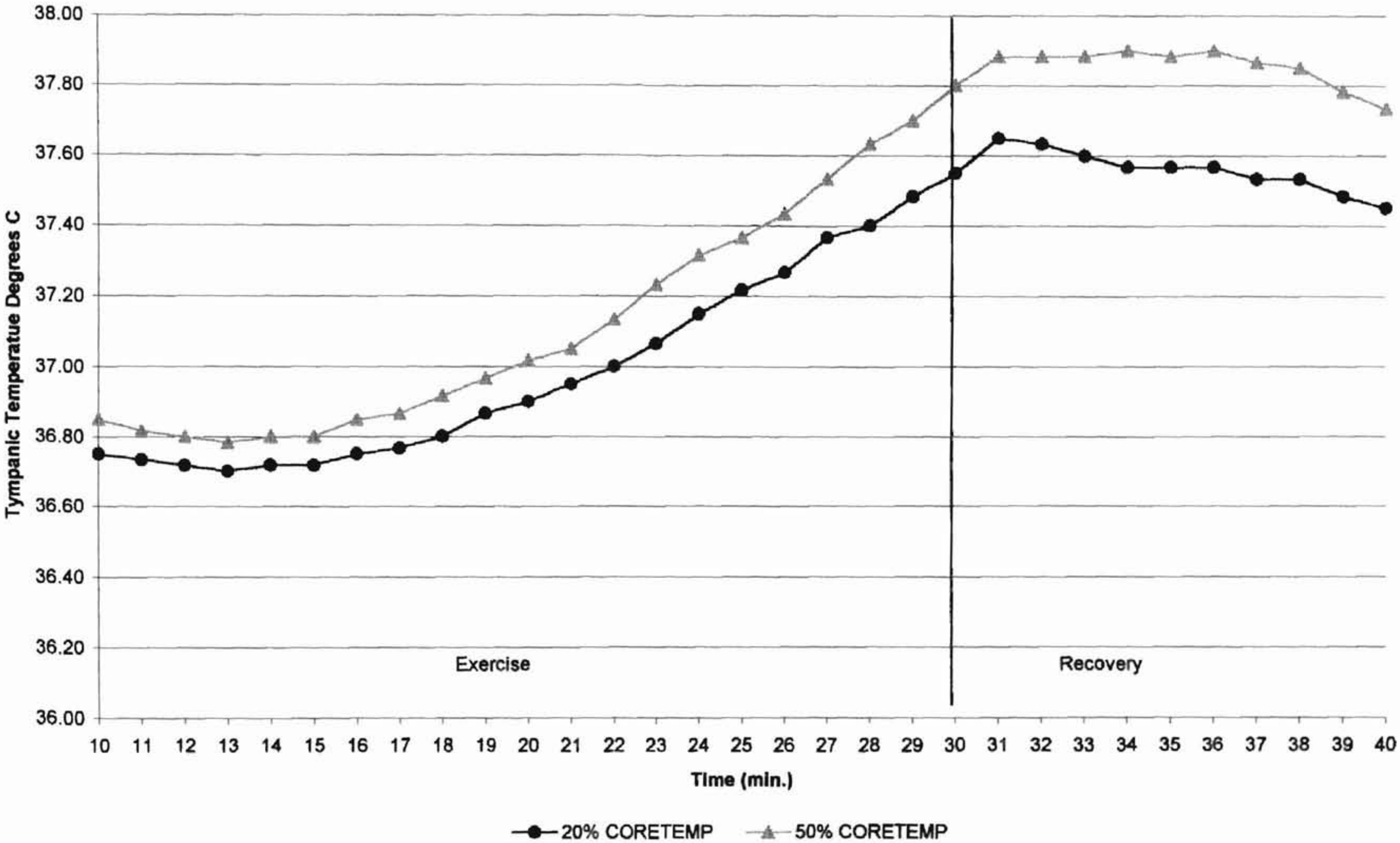


Figure 26: Mean Heart Rate Temperature for suit A for 20% and 50%rh over time

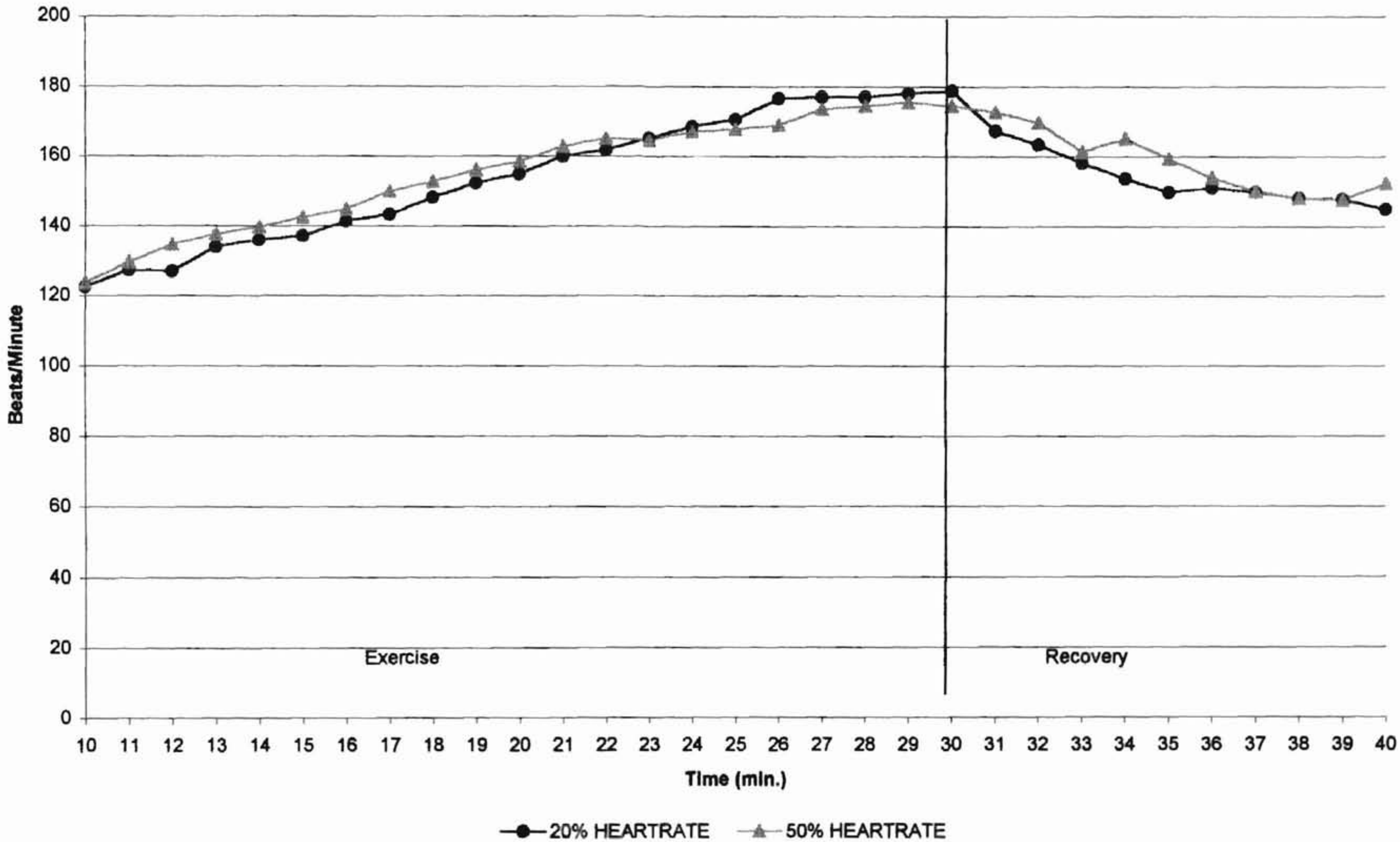


Figure 27: Mean Heart Rate Temperature for suit B for 20% and 50%rh over time

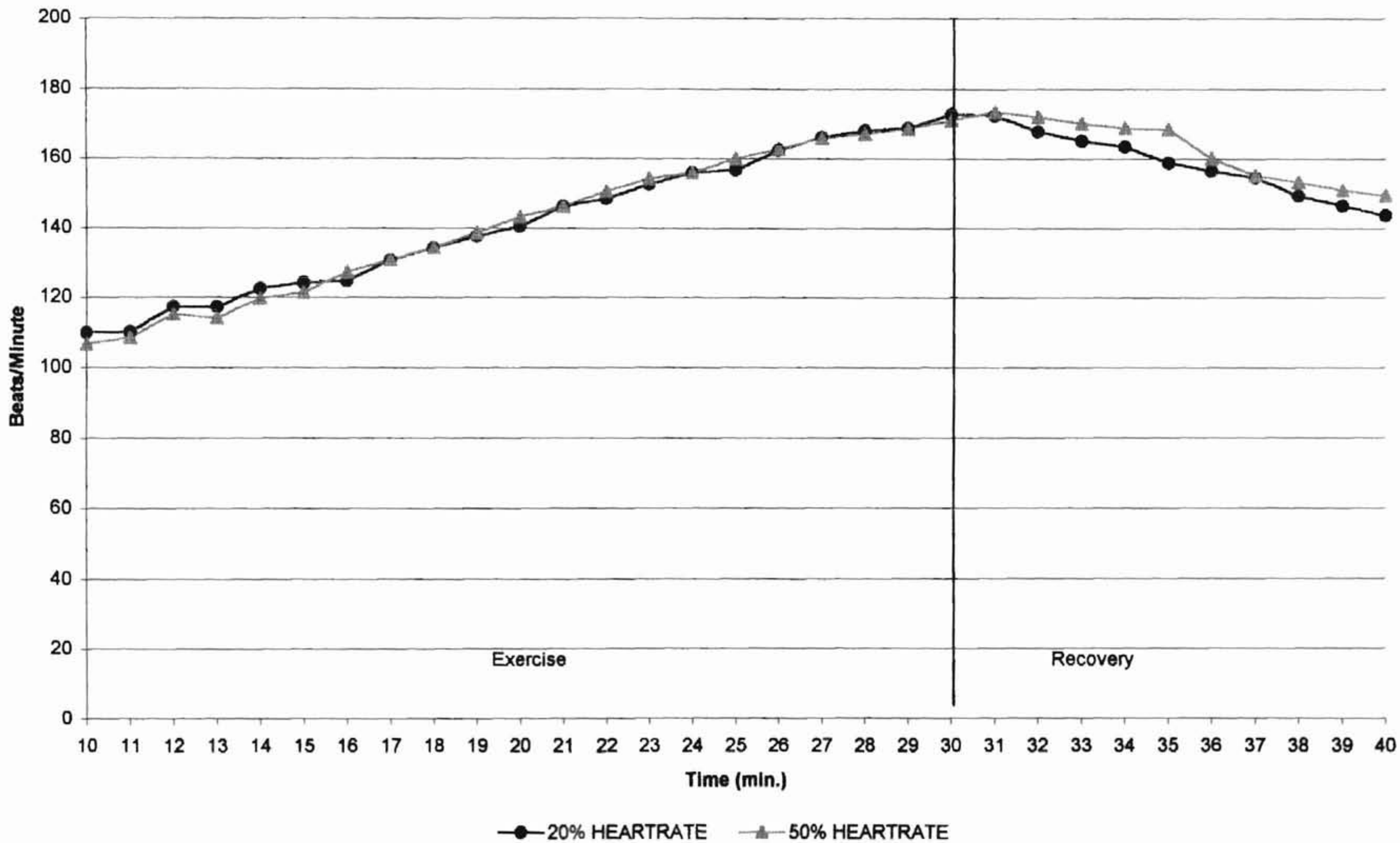


Figure 28: Mean Sweat Rate - Chest for suit A for 20% and 50% rh over time.

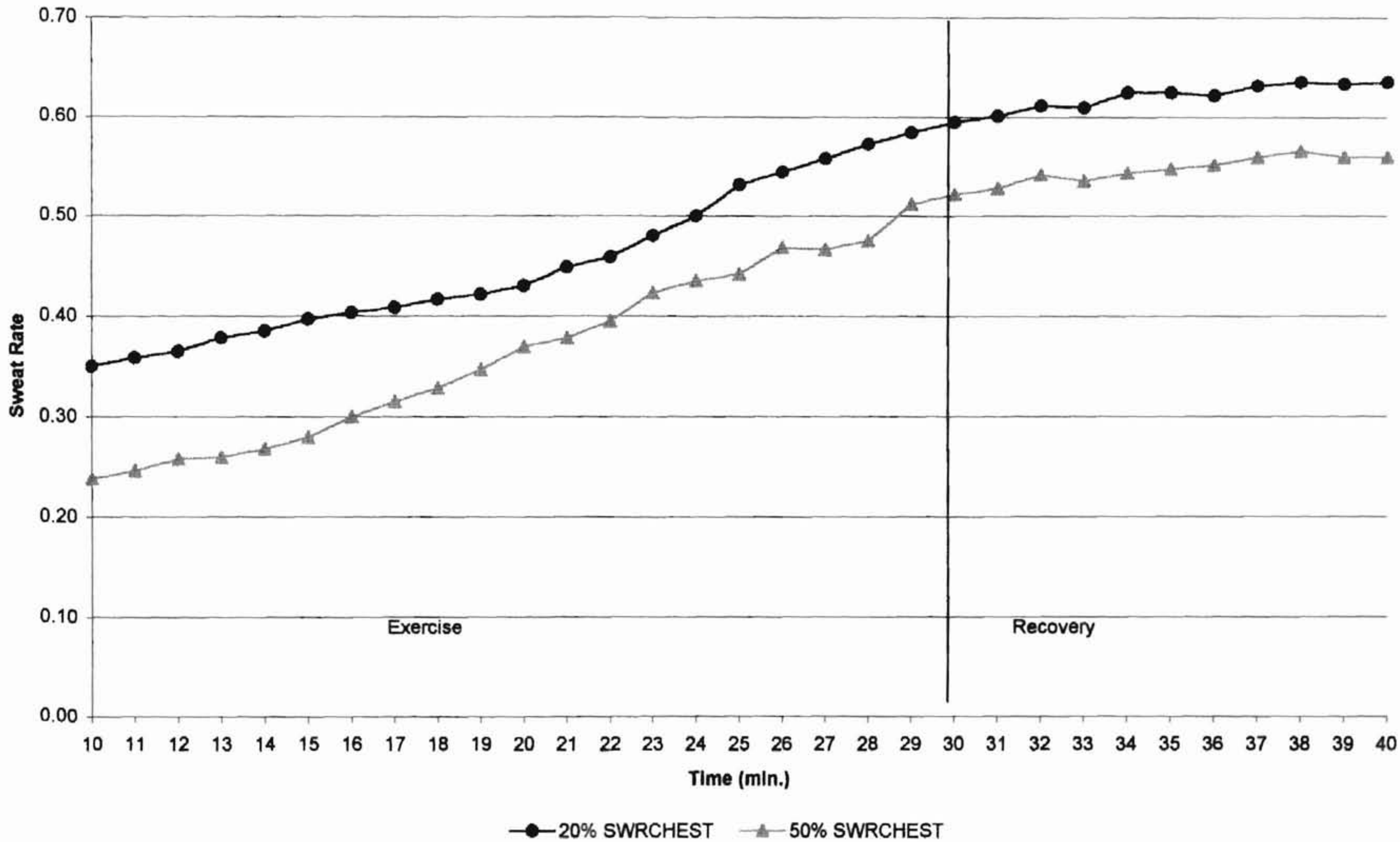


Figure 29: Mean Sweat Rate - Chest for suit B for 20% and 50% rh over time.

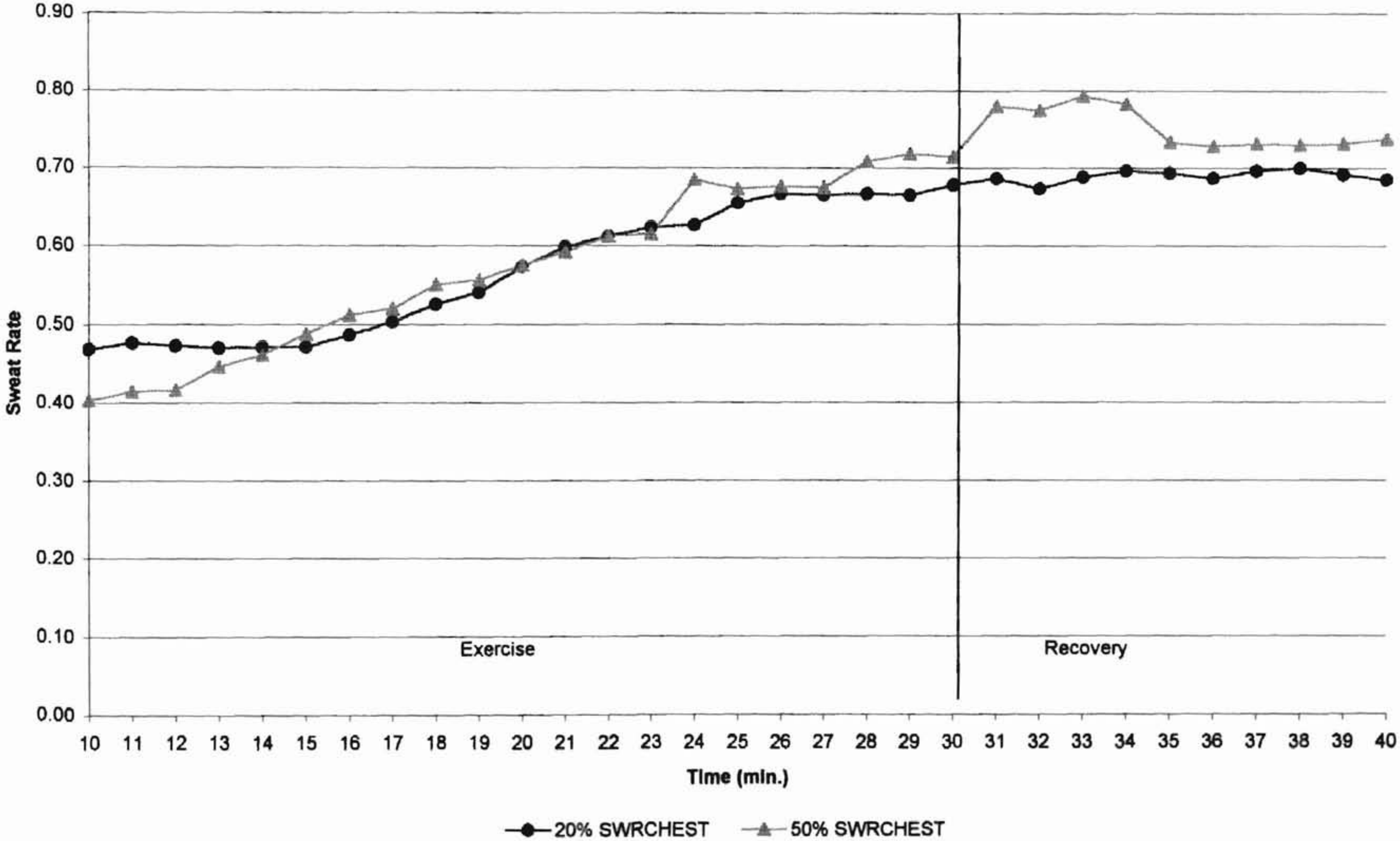


Figure 30: Mean Sweat Rate - Leg for suit A for 20% and 50% rh over time.

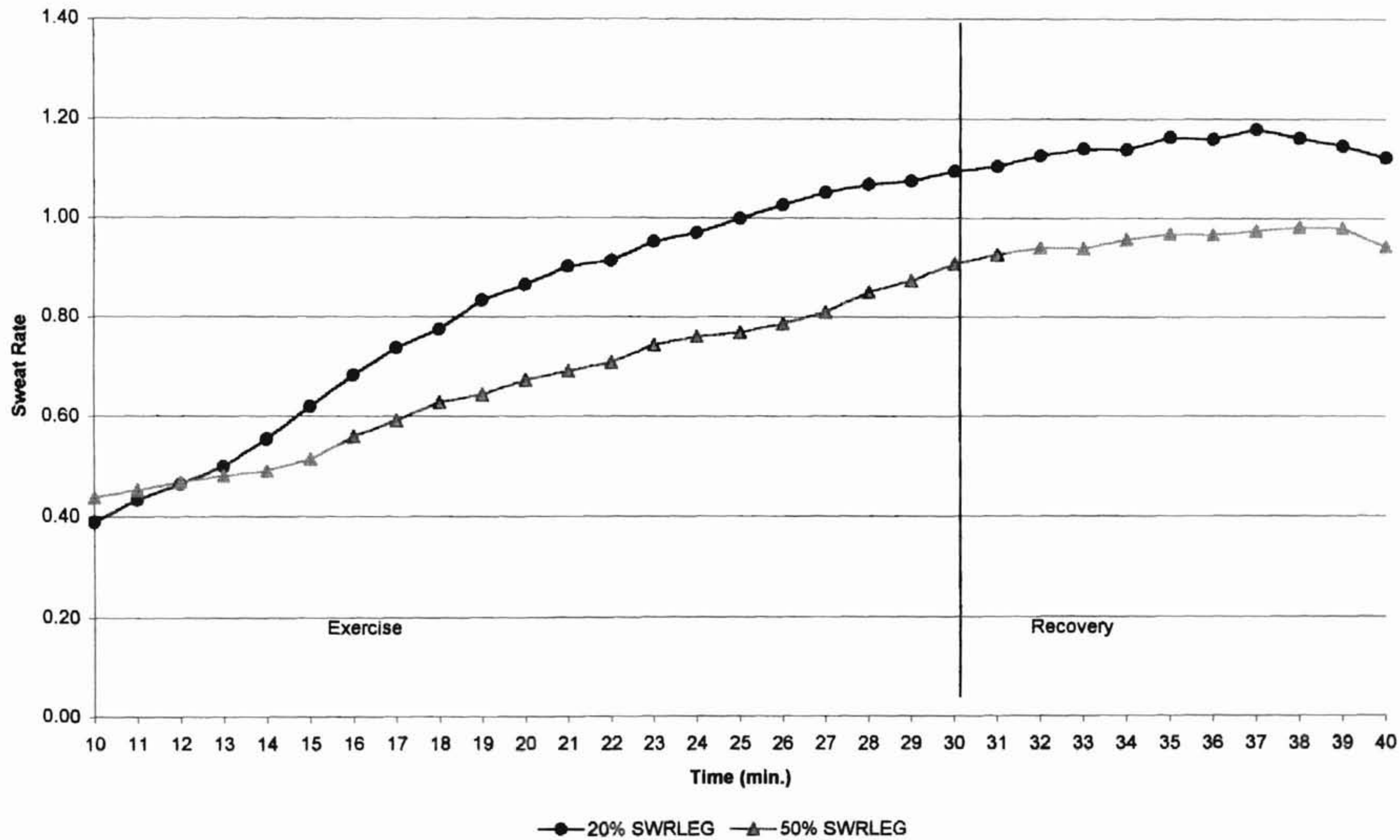


Figure 31: Mean Sweat Rate - Leg for suitB for 20% and 50% rh over time.

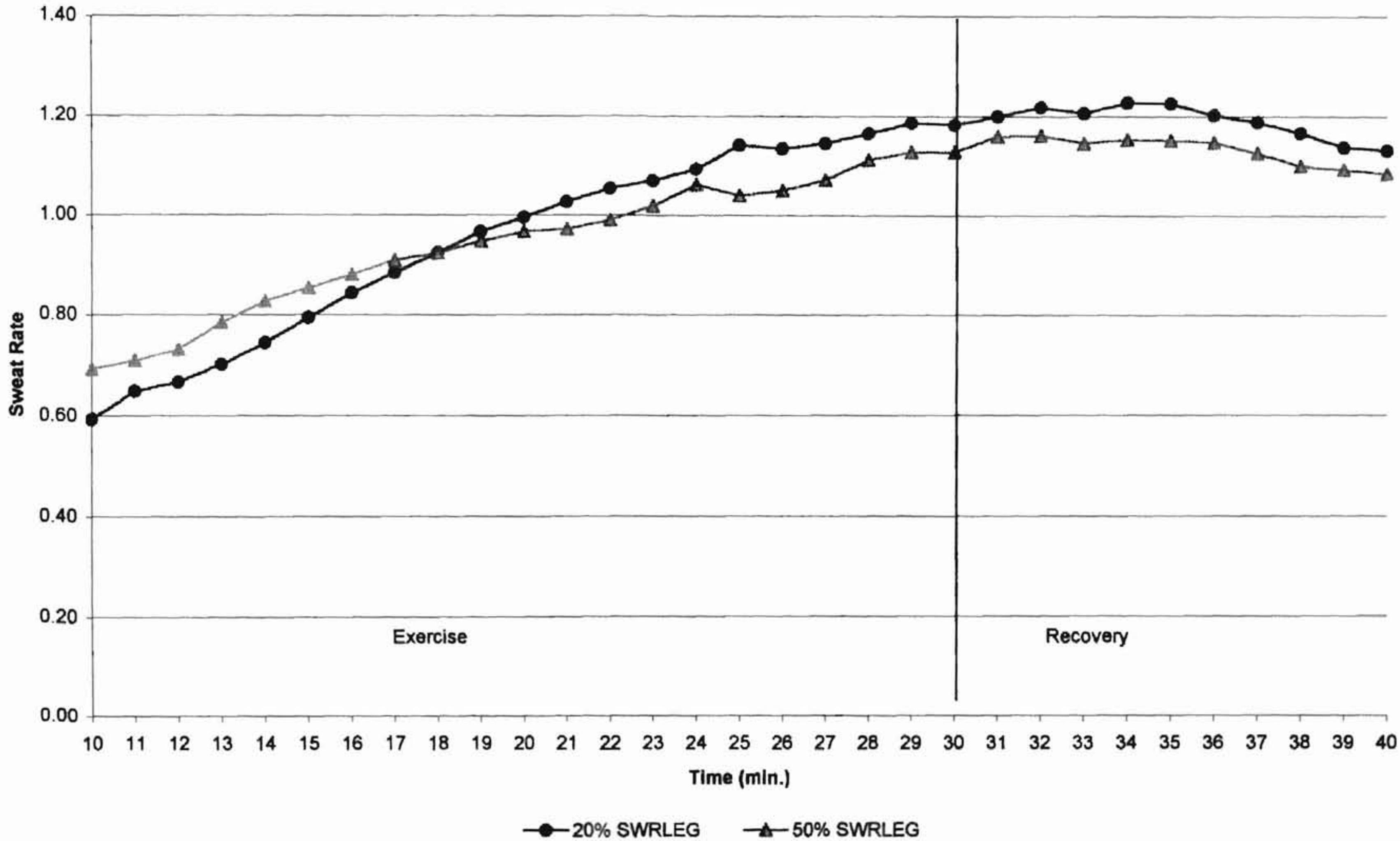


Figure 32: Comfort Descriptor – Absorbent for both suits over time.

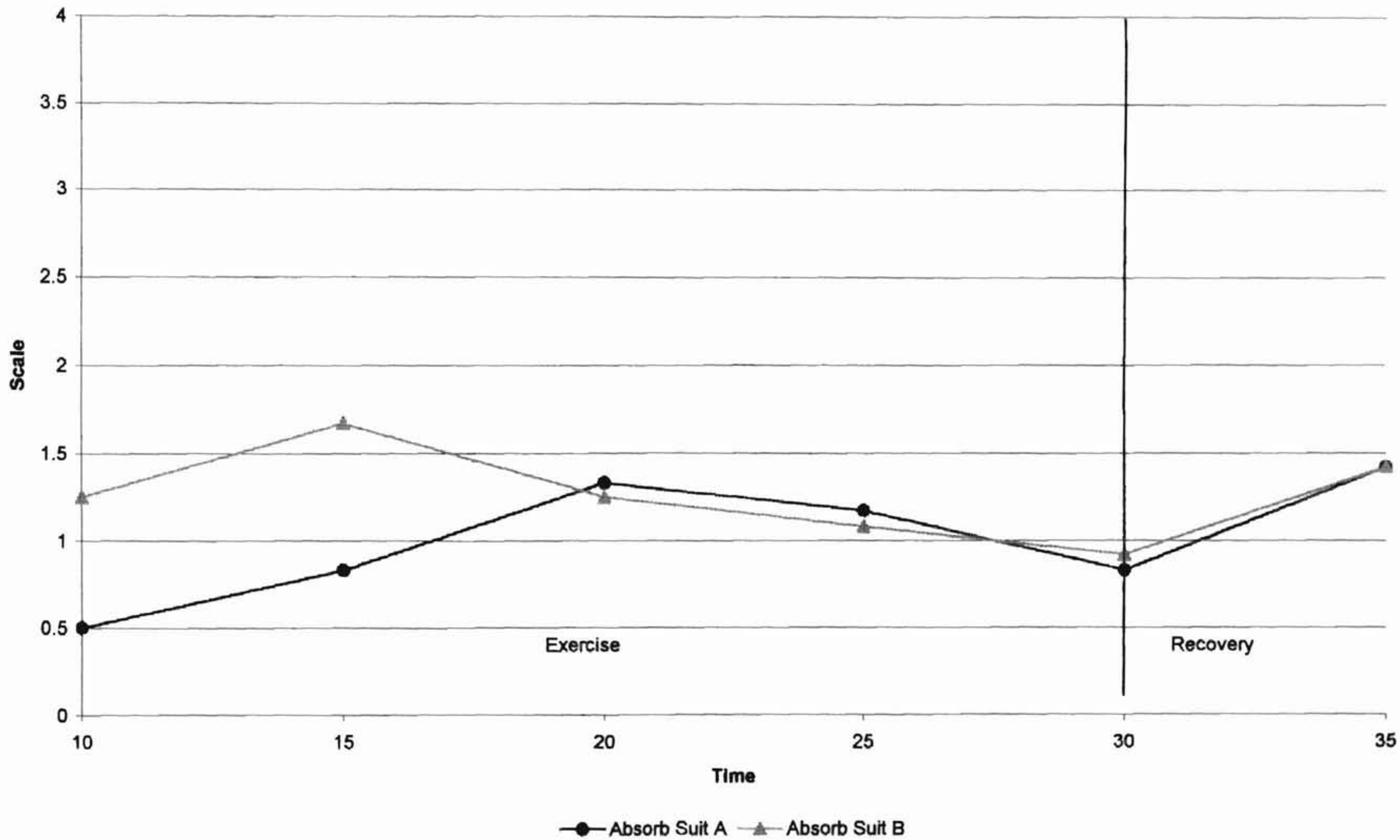


Figure 33: Comfort Descriptor – Breathable for both suits over time.

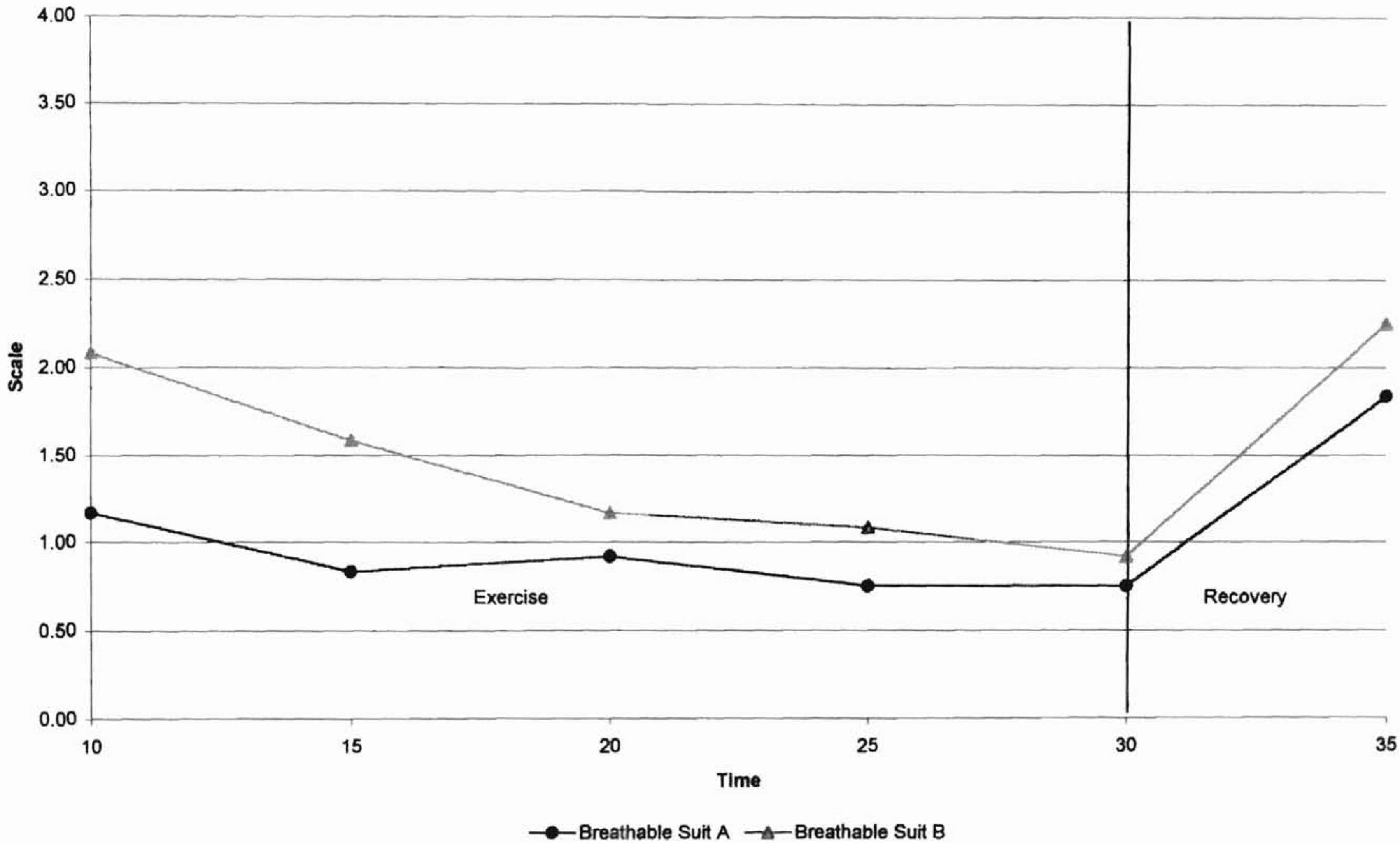


Figure 34: Comfort Descriptor – Clammy for both suits over time.

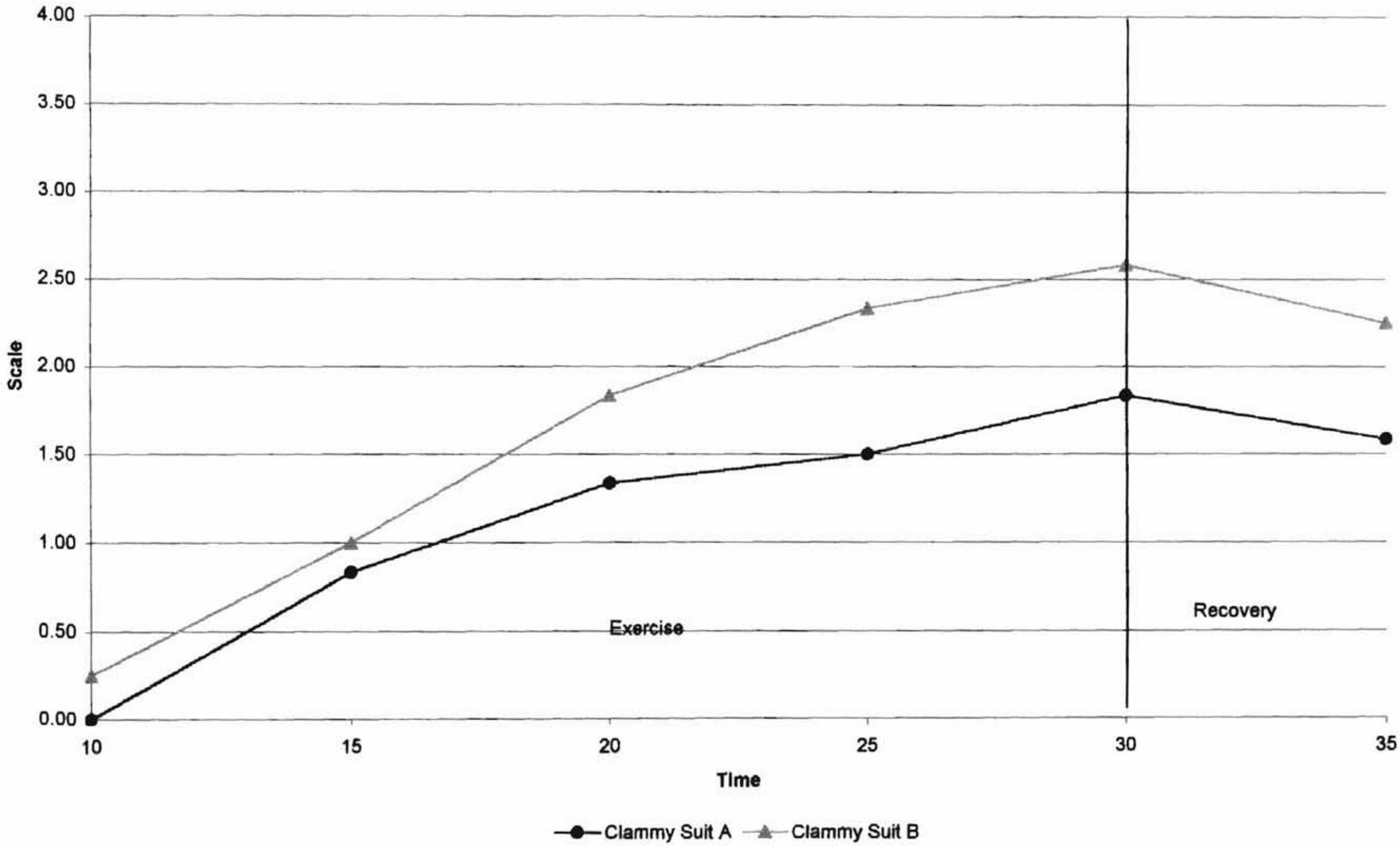


Figure 35: Comfort Descriptor – Clingy for both suits over time.

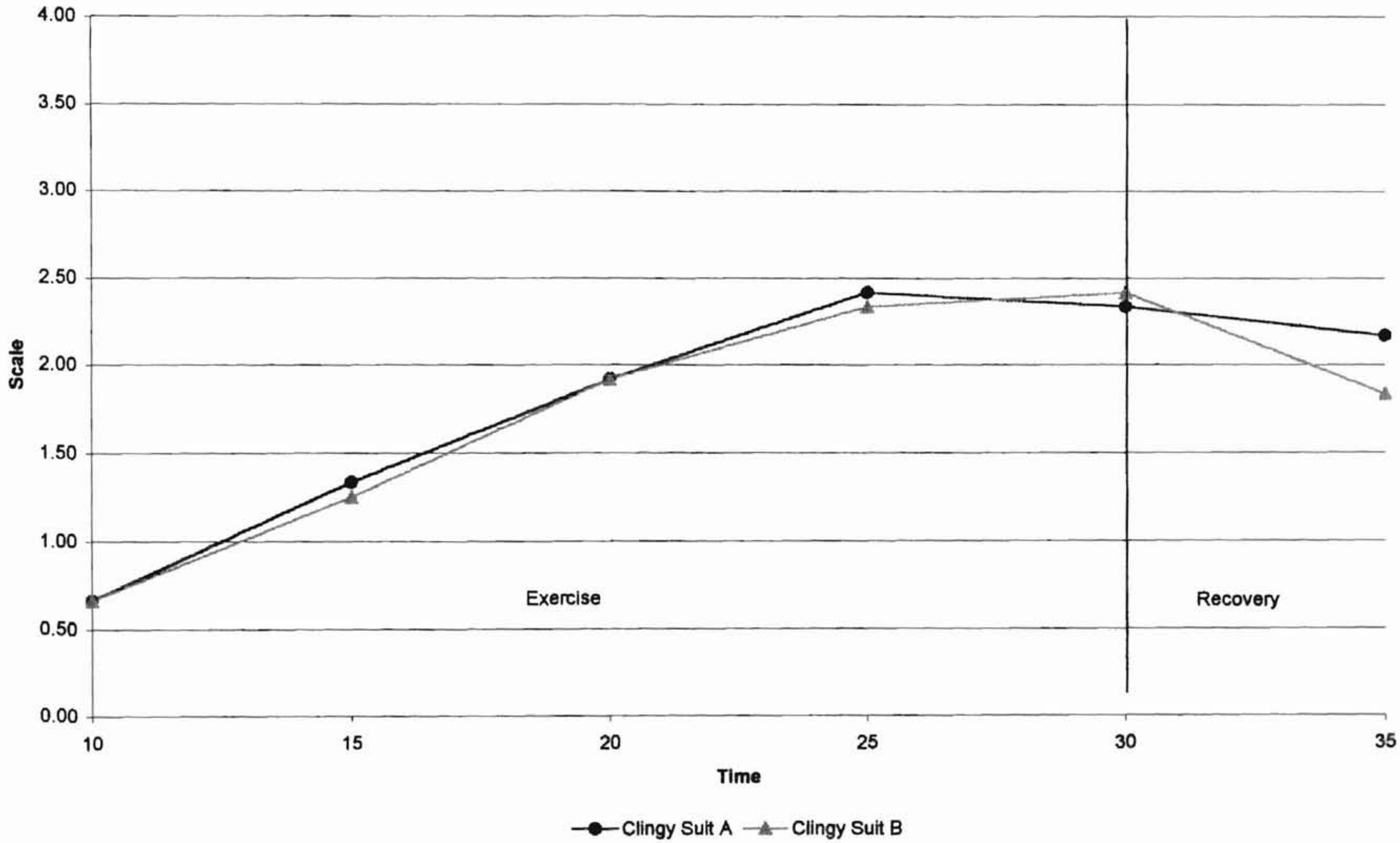


Figure 36: Comfort Descriptor – Comfort for both suits over time.

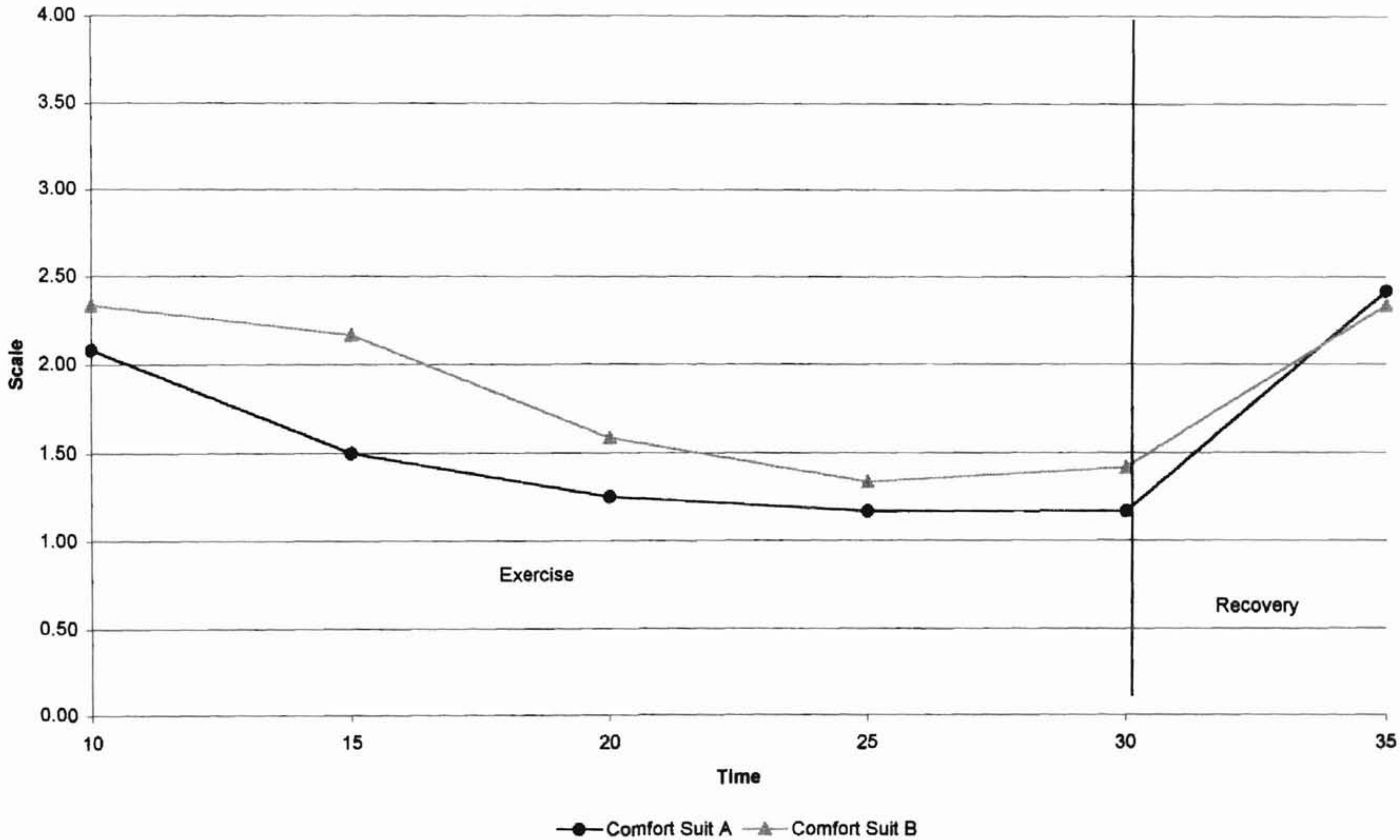


Figure 37: Comfort Descriptor – Constrictive for both suits over time.

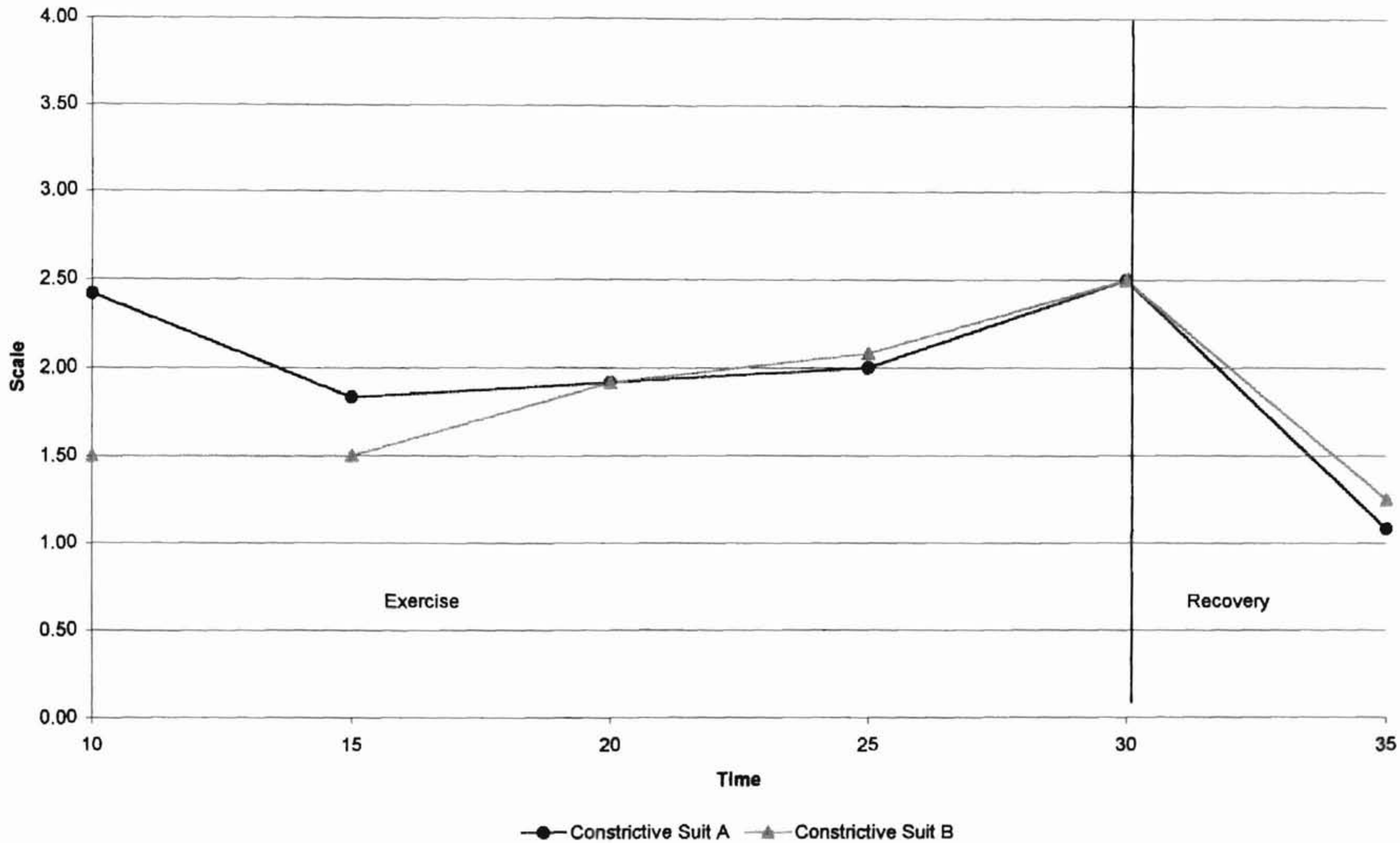


Figure 38: Comfort Descriptor – Damp for both suits over time.

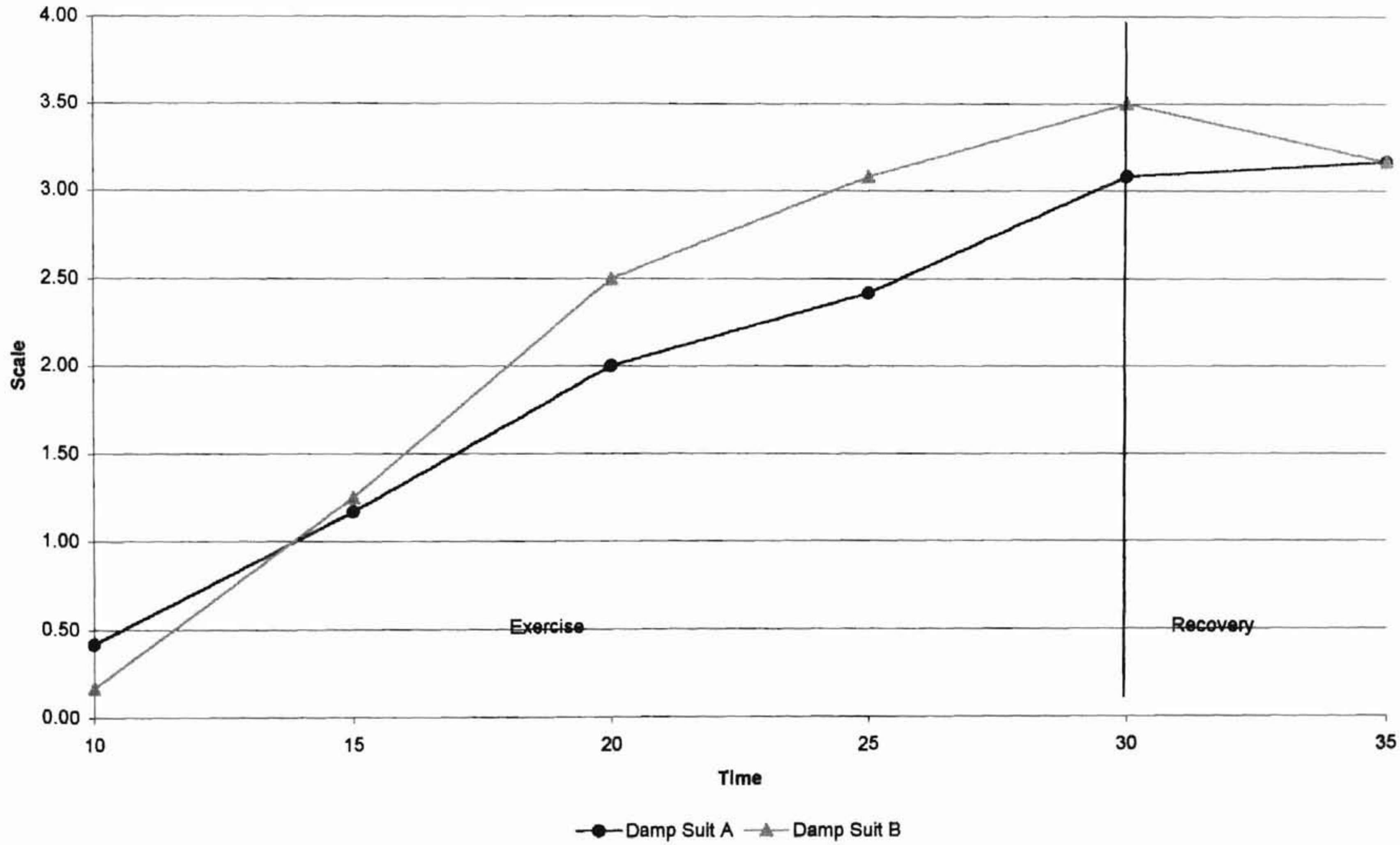


Figure 39: Comfort Descriptor – Dry for both suits over time.

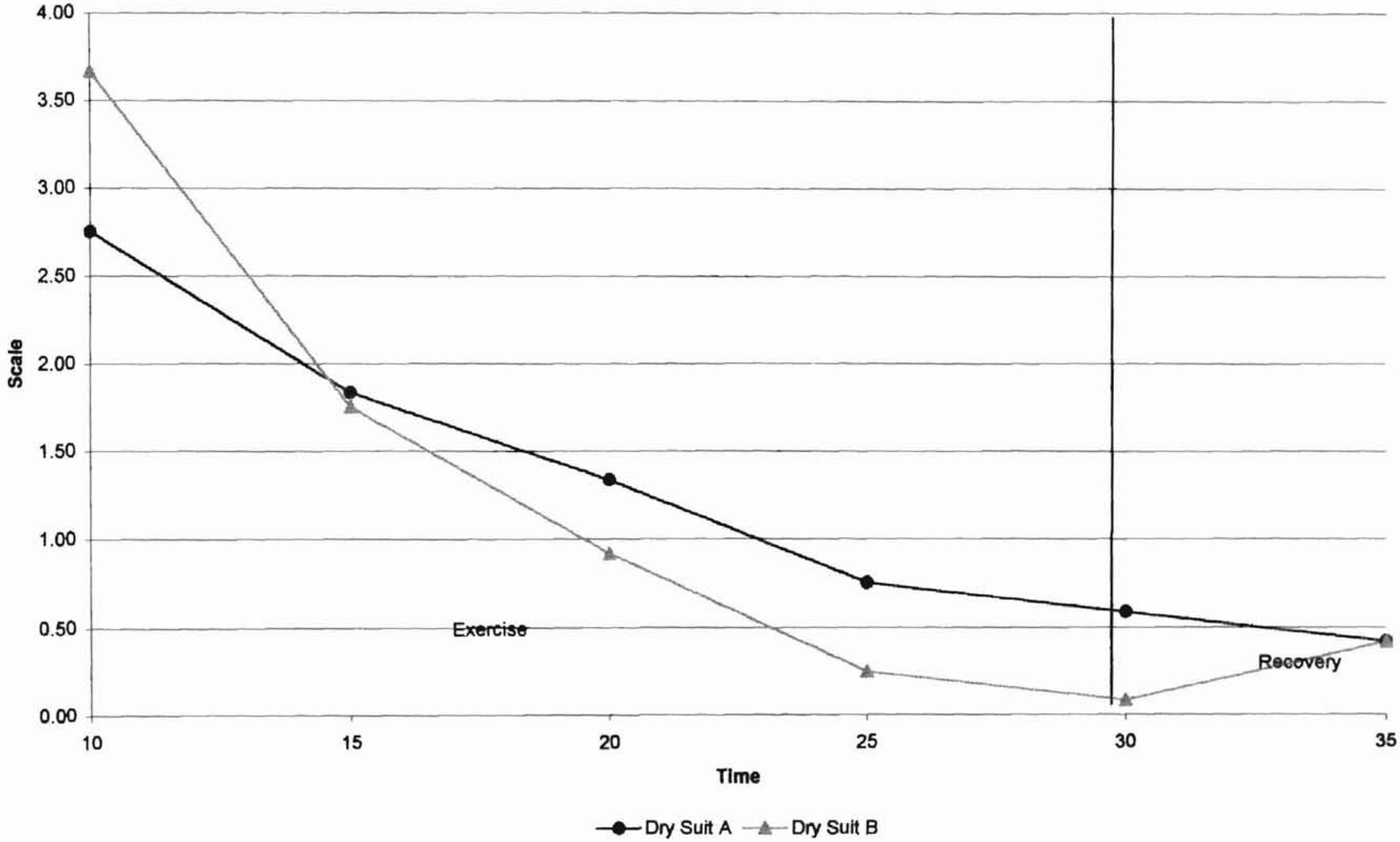


Figure 40: Comfort Descriptor – Flexible for both suits over time.

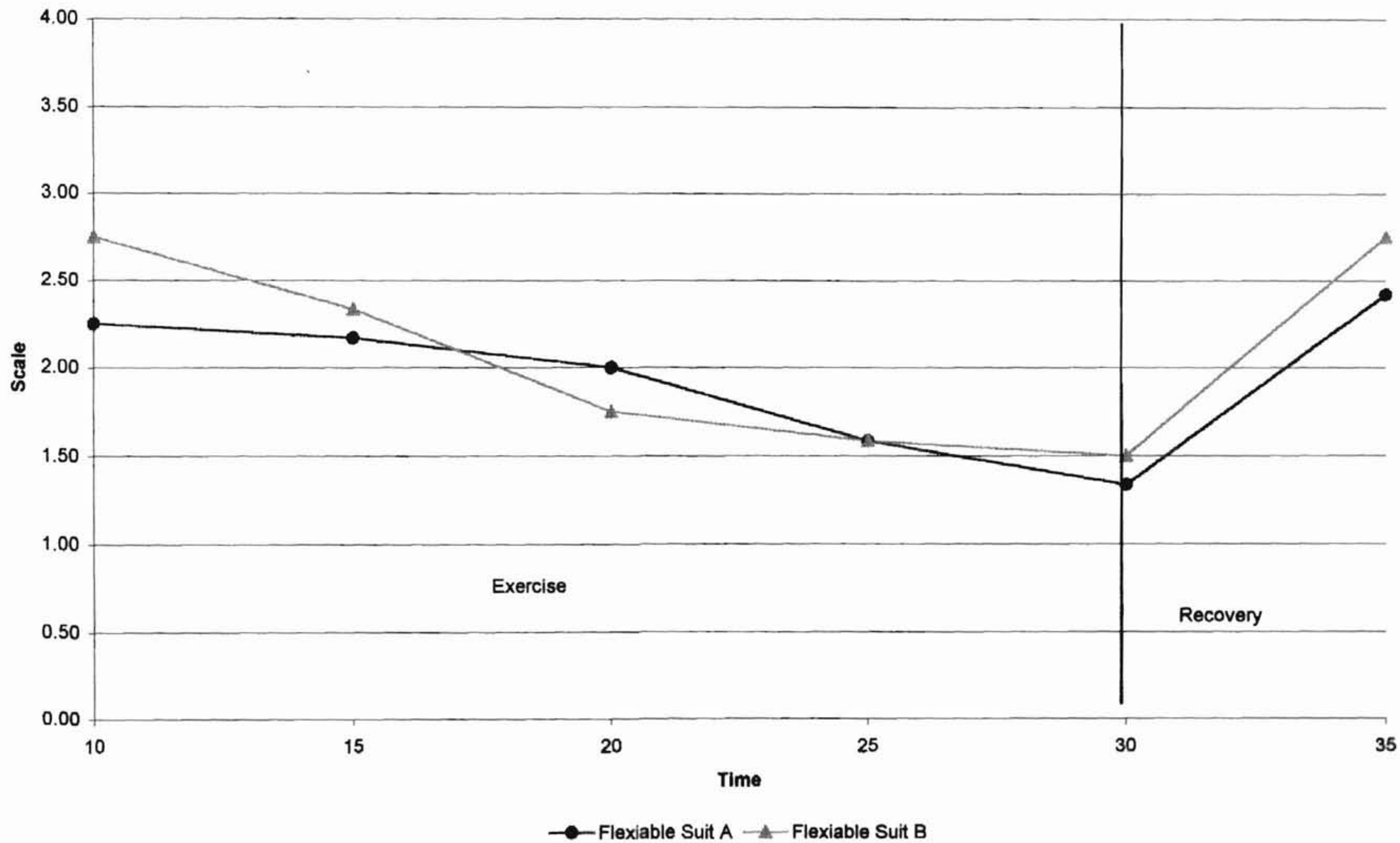


Figure 41: Comfort Descriptor – Heavy for both suits over time.

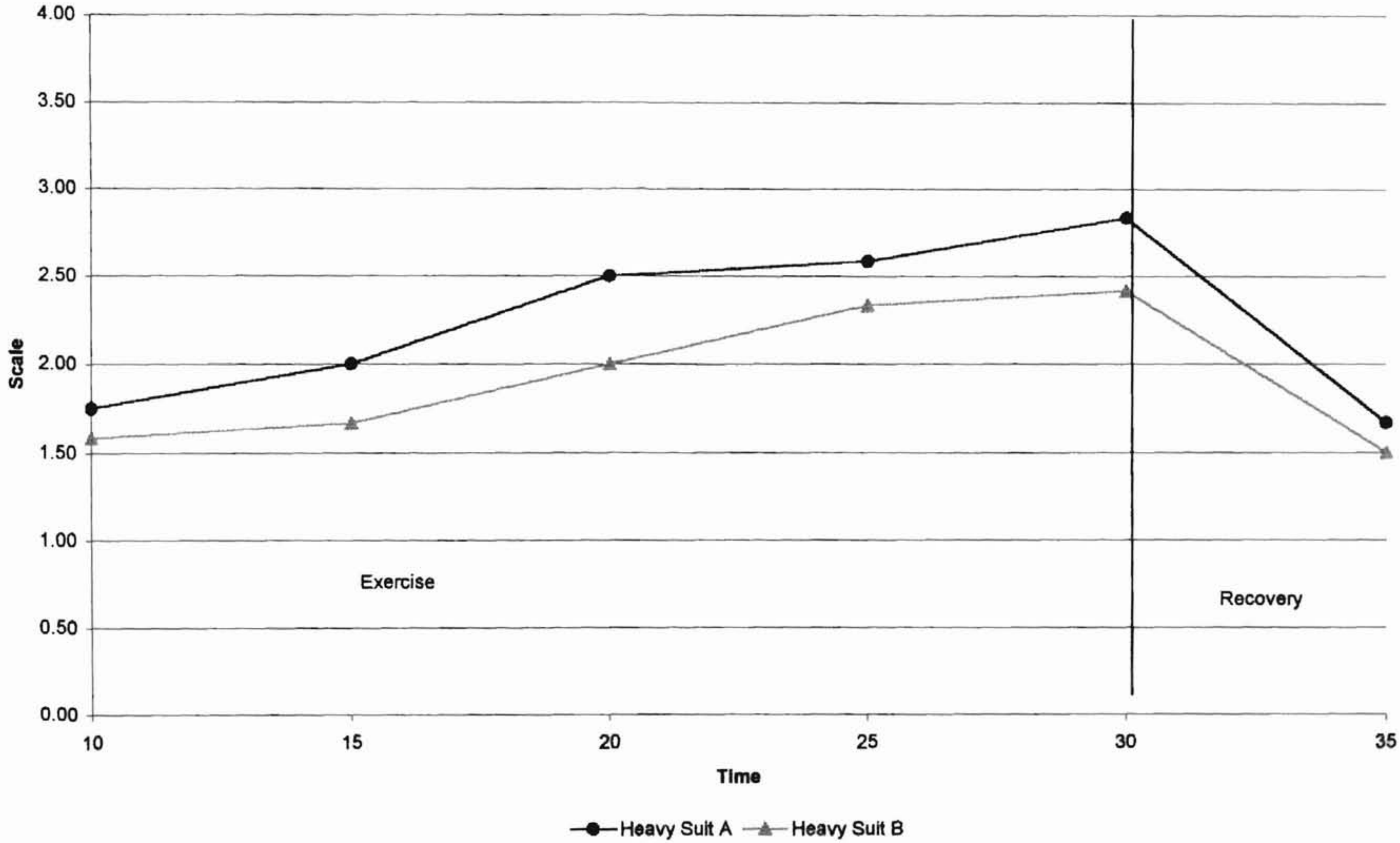


Figure 42: Comfort Descriptor – Hot for both suits over time.

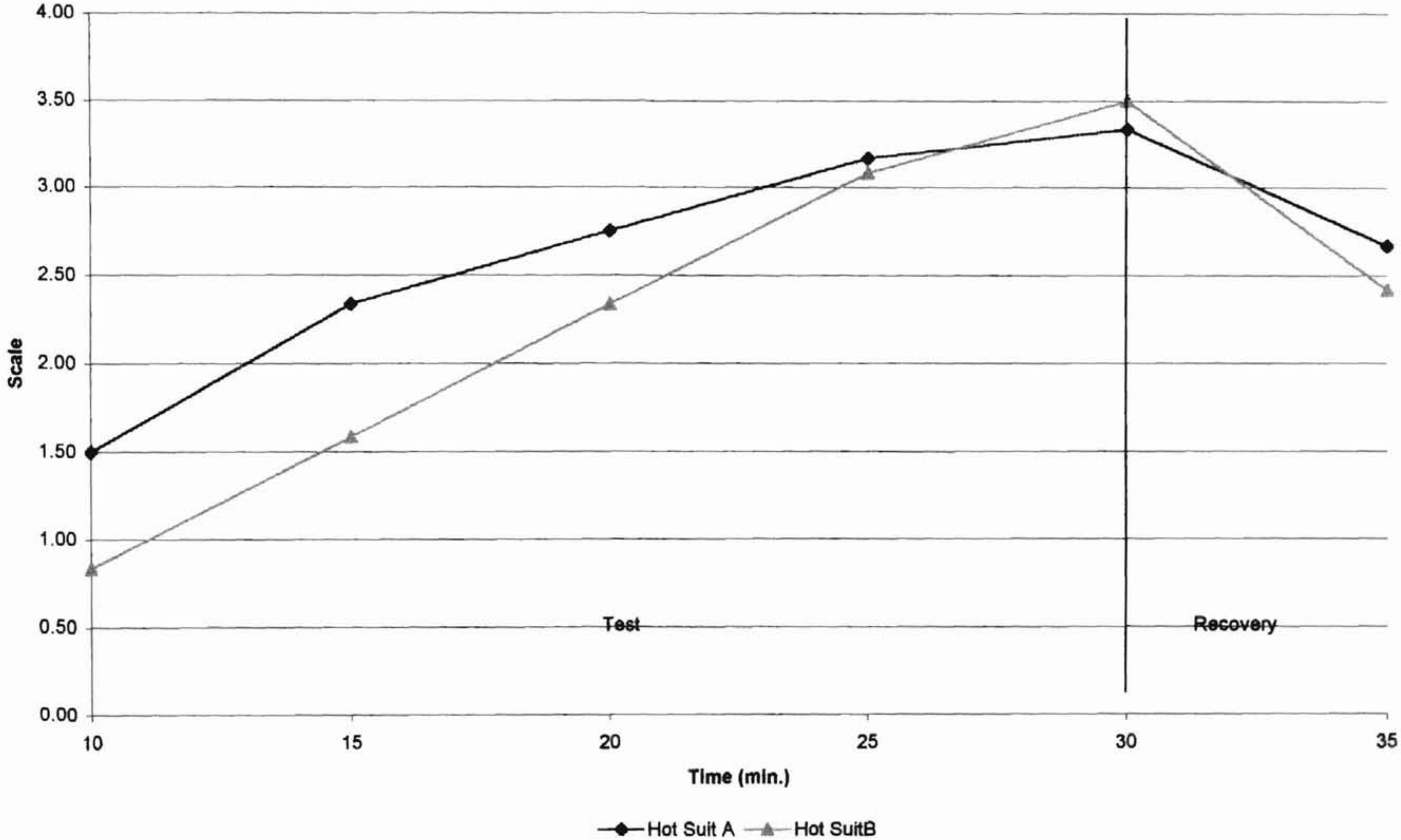


Figure 43: Comfort Descriptor – Snug for both suits over time.

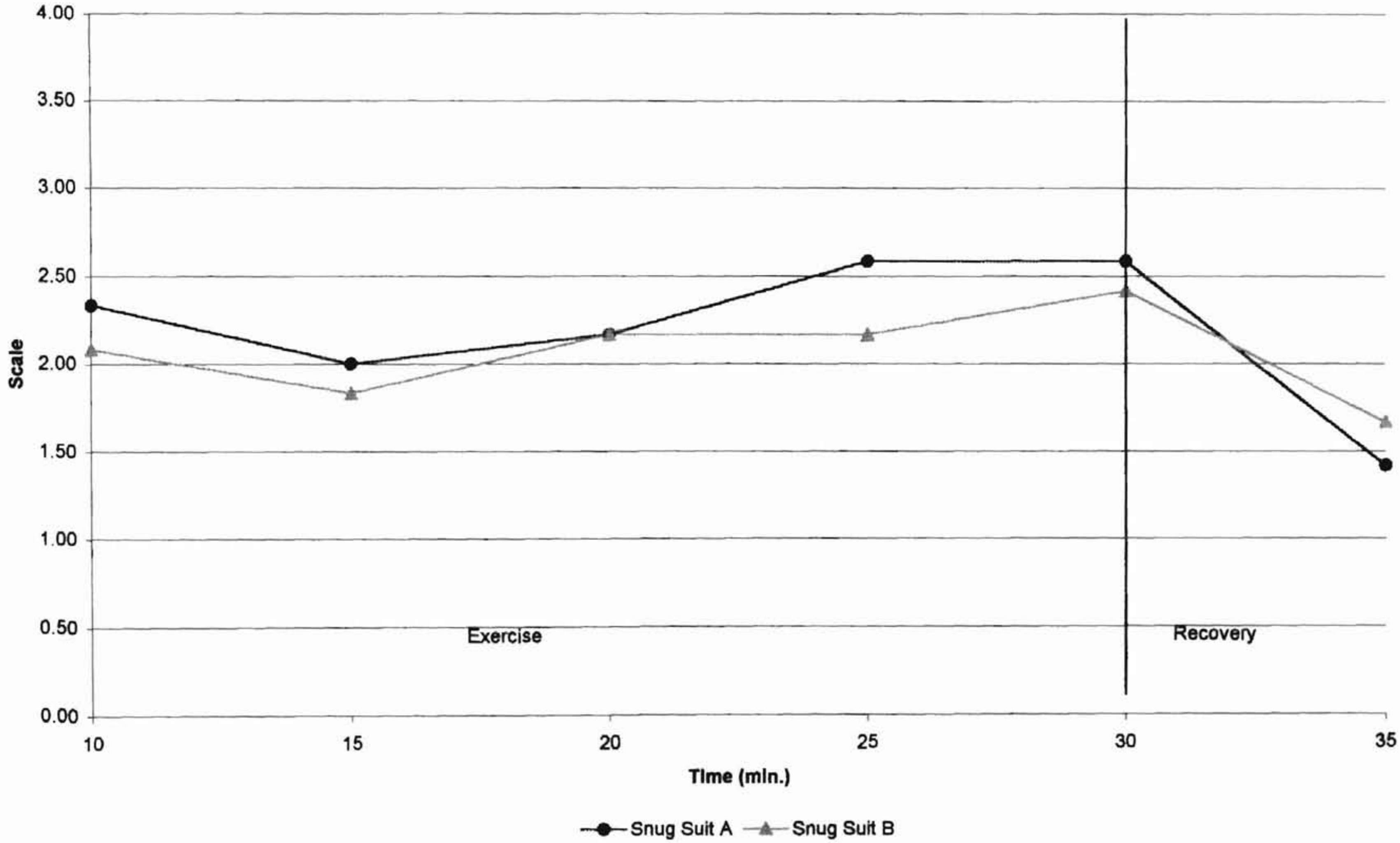


Figure 44: Comfort Descriptor – Stiff for both suits over time.

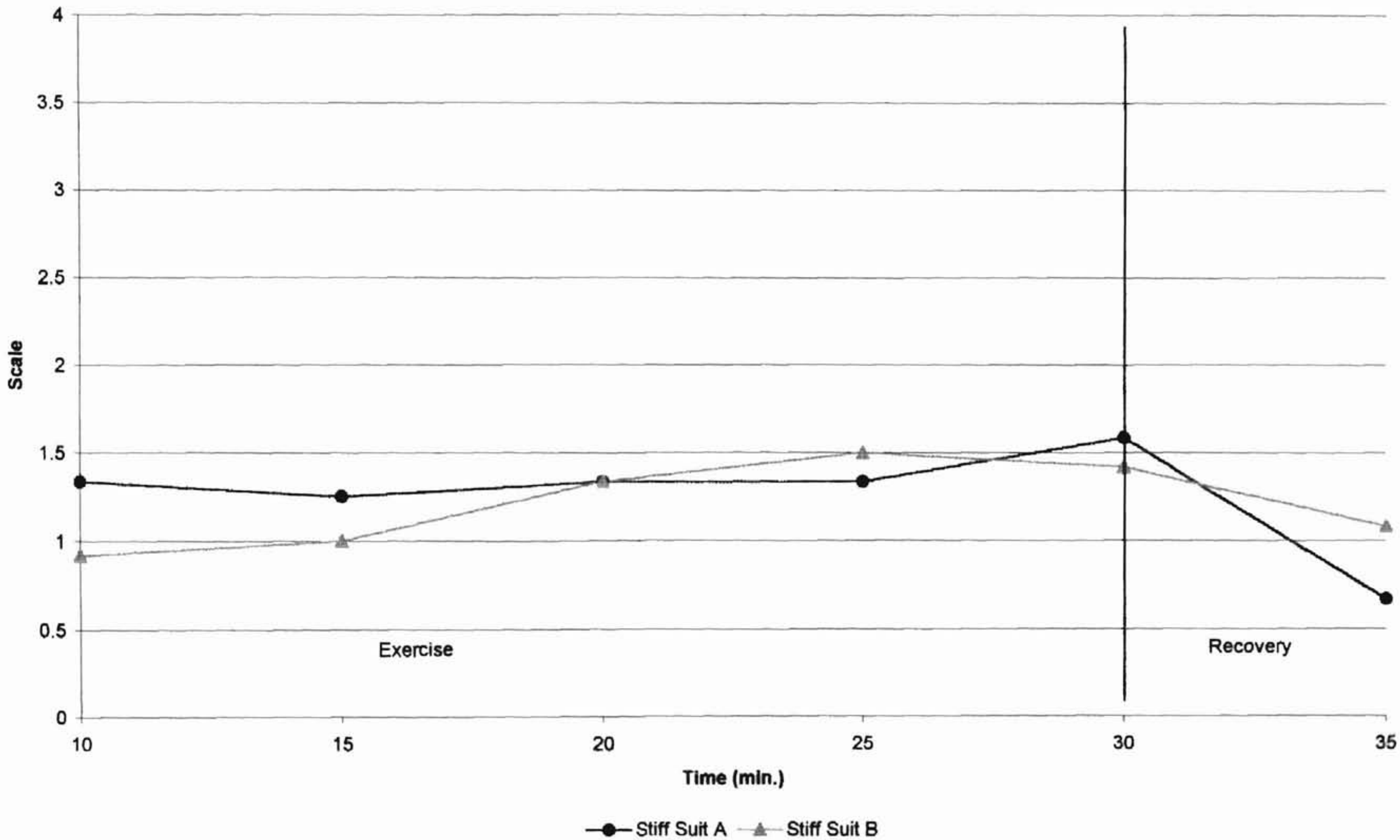


Figure 45: Comfort Descriptor – Thick for both suits over time.

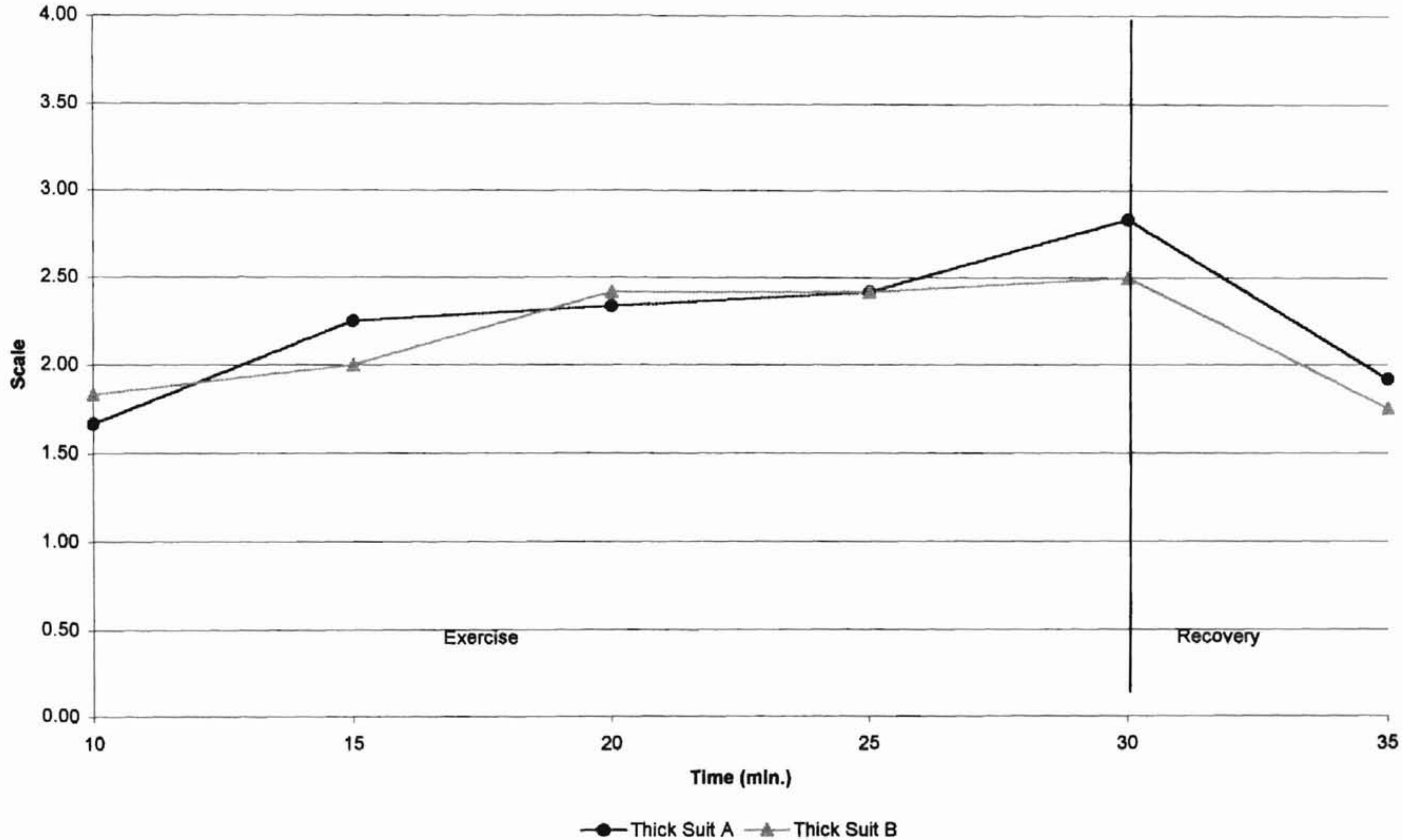


Figure 46: Comfort Descriptor – Warm for both suits over time.

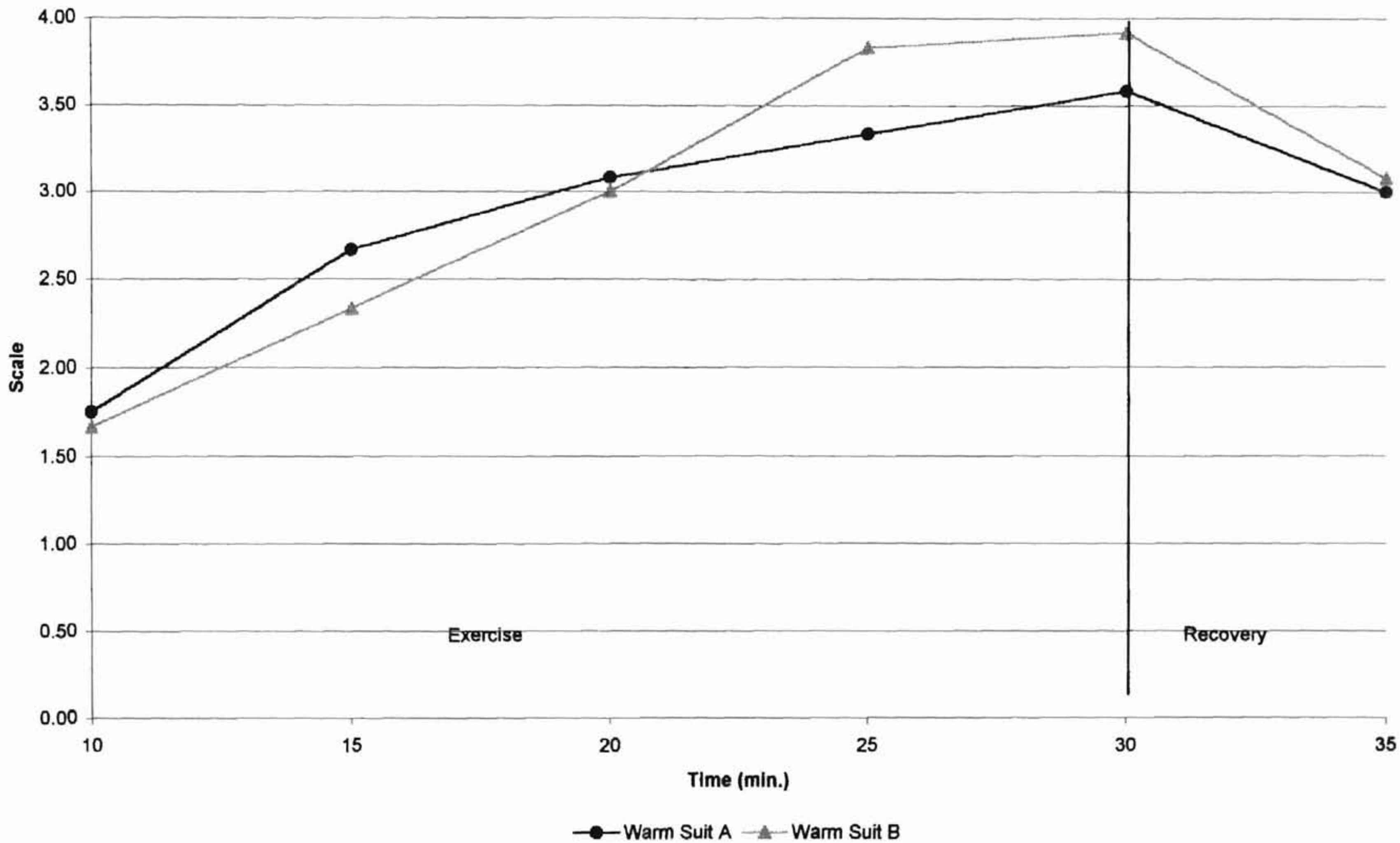
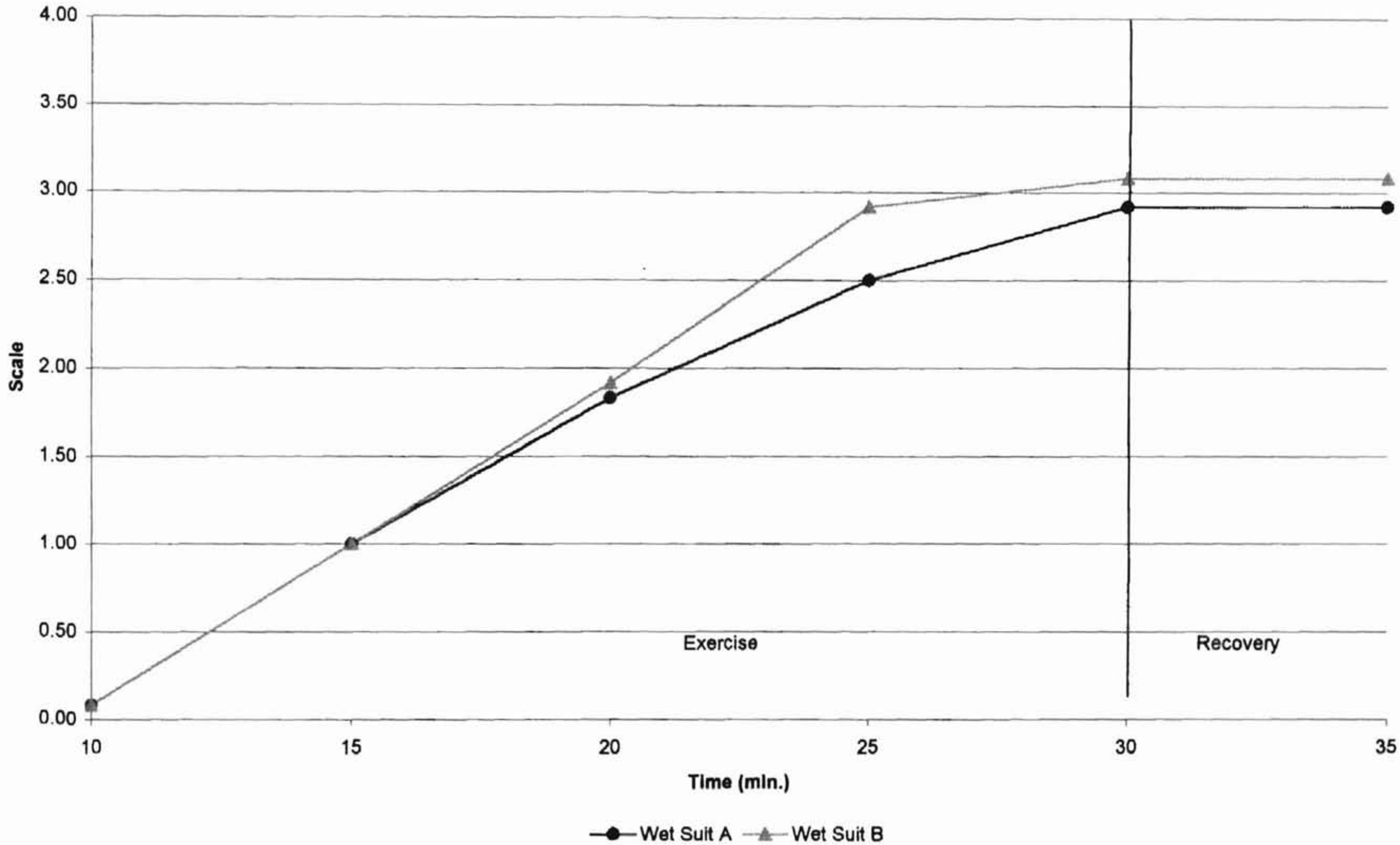


Figure 47: Comfort Descriptor – Wet for both suits over time.



APPENDIX J
ANOVA TABLES

Table 8: Analysis of Variance for Skin Temperature – Chest for Exercise Session (10-30 min.)

Source	DF	Type ISS	Mean Square	F Value	Pr > F
SUBJ	5	134.645821	26.92916421	213.83	0.0001
RH	1	5.90137045	5.90137045	46.86	0.0001
SUBJ*RH	5	64.84061902	12.9681238	102.97	0.0001
SUIT	1	2.7307321	2.7307321	21.68	0.0001
RH*SUIT	1	0.8958393	0.8958393	7.11	0.008
SUIT(SUBJ*RH)	10	109.17207	10.917207	86.69	0.0001
TIME	20	266.3223629	13.31611815	105.74	0.0001
RH*TIME	20	0.51512445	0.02575622	0.2	0.9999
SUIT*TIME	20	5.47411804	0.2737059	2.17	0.0026
RH*SUIT*TIME	20	2.12157222	0.10607861	0.84	0.6614

Table 9: Analysis of Variance for Skin Temperature – Chest for Exercise Session (31-40 min.)

Source	DF	Type ISS	Mean Square	F Value	Pr > F
SUBJ	5	50.66806239	10.13361248	57.36	0.0001
RH	1	6.33041647	6.33041647	35.84	0.0001
SUBJ*RH	5	22.73578353	4.54715671	25.74	0.0001
SUIT	1	9.52224045	9.52224045	53.9	0.0001
RH*SUIT	1	3.42820855	3.42820855	19.41	0.0001
SUIT(SUBJ*RH)	9	63.455266	7.05058511	39.91	0.0001
TIME	9	37.43210478	4.15912275	23.54	0.0001
RH*TIME	9	0.81511461	0.09056829	0.51	0.864
SUIT*TIME	9	5.06412013	0.56268001	3.19	0.0014
RH*SUIT*TIME	9	1.05560914	0.1172899	0.66	0.7406

Table 10: Analysis of Variance for Skin Temperature - Leg for Exercise Session (10-30 min.)

Source	DF	Type ISS	Mean Square	F Value	Pr > F
SUBJ	5	44.03619026	8.80723805	14.31	0.0001
RH	1	0.42601176	0.42601176	0.69	0.4059
SUBJ*RH	5	167.2212749	33.44425498	54.35	0.0001
SUIT	1	3.66748418	3.66748418	5.96	0.0151
RH*SUIT	1	26.79071197	26.79071197	43.54	0.0001
SUIT(SUBJ*RH)	10	141.5490357	14.15490357	23	0.0001
TIME	20	291.1452042	14.55726021	23.66	0.0001
RH*TIME	20	8.42165108	0.42108255	0.68	0.8425
SUIT*TIME	20	8.92130216	0.44606511	0.72	0.801
RH*SUIT*TIME	20	16.51798795	0.8258994	1.34	0.1481

Table 11: Analysis of Variance for Skin Temperature - Leg for Recovery Session (31-40 min.)

Source	DF	Type ISS	Mean Square	F Value	Pr > F
SUBJ	5	209.0892119	41.81784238	307.76	0.0001
RH	1	4.98564828	4.98564828	36.69	0.0001
SUBJ*RH	5	76.23963088	15.24792618	112.22	0.0001
SUIT	1	7.87753136	7.87753136	57.98	0.0001
RH*SUIT	1	1.22291297	1.22291297	9	0.0031
SUIT(SUBJ*RH)	9	189.6938907	21.07709896	155.12	0.0001
TIME	9	14.74859522	1.6387328	12.06	0.0001
RH*TIME	9	0.83479084	0.09275454	0.68	0.724
SUIT*TIME	9	4.18344489	0.46482721	3.42	0.0007
RH*SUIT*TIME	9	1.49028038	0.16558671	1.22	0.2864

Table 12: Analysis of Variance for Skin Temperature – Arm for Exercise Session (10-30 min.)

Source	DF	Type ISS	Mean Square	F Value	Pr > F
SUBJ	5	133.8306724	26.76613448	235.56	0.0001
RH	1	27.42392062	27.42392062	241.35	0.0001
SUBJ*RH	5	151.7284817	30.34569633	267.06	0.0001
SUIT	1	10.52216426	10.52216426	92.6	0.0001
RH*SUIT	1	2.2944982	2.2944982	20.19	0.0001
SUIT(SUBJ*RH)	10	153.9057447	15.39057447	135.45	0.0001
TIME	20	272.2765977	13.61382988	119.81	0.0001
RH*TIME	20	1.09272435	0.05463622	0.48	0.973
SUIT*TIME	20	3.96480079	0.19824004	1.74	0.0248
RH*SUIT*TIME	20	4.17286607	0.2086433	1.84	0.0158

Table 13: Analysis of Variance for Skin Temperature - Arm for Recovery Session (31-40 min.)

Source	DF	Type ISS	Mean Square	F Value	Pr > F
SUBJ	5	96.95148909	19.39029782	26.24	0.0001
RH	1	3.29366711	3.29366711	4.46	0.0362
SUBJ*RH	5	72.76194206	14.55238841	19.69	0.0001
SUIT	1	57.71264727	57.71264727	78.1	0.0001
RH*SUIT	1	4.02560606	4.02560606	5.45	0.0208
SUIT(SUBJ*RH)	9	141.6677067	15.7408563	21.3	0.0001
TIME	9	79.60928739	8.84547638	11.97	0.0001
RH*TIME	9	2.05584837	0.2284276	0.31	0.9712
SUIT*TIME	9	20.08599646	2.23177738	3.02	0.0023
RH*SUIT*TIME	9	2.14437911	0.23826435	0.32	0.9668

Table 14: Analysis of Variance for Mean Weighted Skin Temperature for Exercise Session (10-30 min.)

Source	DF	Type ISS	Mean Square	F Value	Pr > F
SUBJ	5	50.36114532	10.07222906	57.74	0.0001
RH	1	2.93373966	2.93373966	16.82	0.0001
SUBJ*RH	5	83.31694246	16.66338849	95.52	0.0001
SUIT	1	3.8801164	3.8801164	22.24	0.0001
RH*SUIT	1	4.51362067	4.51362067	25.87	0.0001
SUIT(SUBJ*RH)	10	64.34136265	6.43413626	36.88	0.0001
TIME	20	274.7080089	13.73540045	78.73	0.0001
RH*TIME	20	1.28040463	0.06402023	0.37	0.995
SUIT*TIME	20	5.19604817	0.25980241	1.49	0.0808
RH*TIME*TIME	20	2.10004964	0.10500248	0.6	0.9117

Table 15: Analysis of Variance for Weighted Mean Skin Temperature for Recovery Session (31-40

Source	DF	Type ISS	Mean Square	F Value	Pr > F
SUBJ	5	86.35881979	17.27176396	116.28	0.0001
RH	1	0.50164084	0.50164084	3.38	0.0678
SUBJ*RH	5	41.45111649	8.2902233	55.81	0.0001
SUIT	1	13.08182095	13.08182095	88.07	0.0001
RH*SUIT	1	0.65376679	0.65376679	4.4	0.0374
SUIT(SUBJ*RH)	9	58.89302042	6.54366894	44.06	0.0001
TIME	9	9.71899251	1.07988806	7.27	0.0001
RH*TIME	9	0.32926418	0.03658491	0.25	0.9869
SUIT*TIME	9	4.8362141	0.53735712	3.62	0.0004
RH*SUIT*TIME	9	0.76250942	0.08472327	0.57	0.8201

Table 16: Analysis of Variance for Core Temperature for Exercise Session (10-30 min.)

Source	DF	Type ISS	Mean Square	F Value	Pr > F
SUBJ	5	34.71400899	6.9428018	359.81	0.0001
RH	1	0.52741521	0.52741521	27.33	0.0001
SUBJ*RH	5	20.99042857	4.19808571	217.56	0.0001
SUIT	1	9.63501016	9.63501016	499.33	0.0001
RH*SUIT	1	0.56028202	0.56028202	29.04	0.0001
SUIT(SUBJ*RH)	10	31.94284315	3.19428432	165.54	0.0001
TIME	20	49.51558788	2.47577939	128.31	0.0001
RH*TIME	20	0.16986894	0.00849345	0.44	0.984
SUIT*TIME	20	0.18298969	0.00914948	0.47	0.9751
RH*SUIT*TIME	20	0.49672642	0.02483632	1.29	0.1829

Table 17: Analysis of Variance for Core Temperature for Recovery Session (31-40 min.)

Source	DF	Type ISS	Mean Square	F Value	Pr > F
SUBJ	5	7.03466304	1.40693261	67.98	0.0001
RH	1	1.00592647	1.00592647	48.6	0.0001
SUBJ*RH	5	11.71032353	2.34206471	113.16	0.0001
SUIT	1	10.648	10.648	514.48	0.0001
RH*SUIT	1	1.00393333	1.00393333	48.51	0.0001
SUIT(SUBJ*RH)	9	13.35906667	1.48434074	71.72	0.0001
TIME	9	0.59152174	0.06572464	3.18	0.0014
RH*TIME	9	0.03702372	0.00411375	0.2	0.9941
SUIT* TIME	9	0.01967677	0.00218631	0.11	0.9995
RH*SUIT*TIME	9	0.01964444	0.00218272	0.11	0.9995

Table 18: Analysis of Variance for Heart Rate for Exercise Session (10-30 min.)

Source	DF	Type ISS	Mean Square	F Value	Pr > F
SUBJ	5	31423.40455	6284.68091	120.66	0.0001
RH	1	20.34233	20.34233	0.39	0.5324
SUBJ*RH	5	9150.3458	1830.06916	35.14	0.0001
SUIT	1	23088.73724	23088.73724	443.3	0.0001
RH*SUIT	1	57.84895	57.84895	1.11	0.2926
SUIT(SUBJ*RH)	10	27620.7264	2762.07264	53.03	0.0001
TIME	20	179383.0534	8969.15267	172.2	0.0001
RH*TIME	20	435.47254	21.77363	0.42	0.9884
SUIT*TIME	20	1441.22791	72.0614	1.38	0.1257
RH*SUIT*TIME	20	643.9586	32.19793	0.62	0.8998

Table 19: Analysis of Variance for Heart Rate for Recovery Session (31-40 min.)

Source	DF	Type ISS	Mean Square	F Value	Pr > F
SUBJ	5	35660.31087	7132.062174	166.16	0.0001
RH	1	1286.470588	1286.470588	29.97	0.0001
SUBJ*RH	5	1588.679412	317.735882	7.4	0.0001
SUIT	1	928.654545	928.654545	21.64	0.0001
RH*SUIT	1	4.963788	4.963788	0.12	0.7342
SUIT(SUBJ*RH)	9	9676.981667	1075.220185	25.05	0.0001
TIME	9	14940.69565	1660.077295	38.68	0.0001
RH*TIME	9	453.158136	50.350904	1.17	0.3152
SUIT*TIME	9	580.208117	64.467569	1.5	0.1506
RH*SUIT*TIME	9	152.318095	16.924233	0.39	0.9366

Table 20: Analysis of Variance for Sweat Rate – Chest for Exercise Session (10-30min.)

Source	DF	Type ISS	Mean Square	F Value	Pr > F
SUBJ	5	0.47876156	0.09575231	44.81	0.0001
RH	1	0.22612882	0.22612882	105.82	0.0001
SUBJ*RH	5	1.2555822	0.25111644	117.52	0.0001
SUIT	1	3.18748756	3.18748756	1491.69	0.0001
RH*SUIT	1	0.2977678	0.2977678	139.35	0.0001
SUIT(SUBJ*RH)	10	1.89941209	0.18994121	88.89	0.0001
TIME	20	3.7464042	0.18732021	87.66	0.0001
RH*TIME	20	0.06054809	0.0030274	1.42	0.1098
SUIT*TIME	20	0.03242103	0.00162105	0.76	0.7634
RH*SUIT*TIME	20	0.03356744	0.00167837	0.79	0.7319

Table 21: Analysis of Variance for Sweat Rate – Chest for Recovery Session (31-40 min.)

Source	DF	Type ISS	Mean Square	F Value	Pr > F
SUBJ	5	0.43763768	0.08752754	78.19	0.0001
RH	1	0.00003314	0.00003314	0.03	0.8636
SUBJ*RH	5	1.32021353	0.26404271	235.89	0.0001
SUIT	1	1.19290909	1.19290909	1065.7	0.0001
RH*SUIT	1	0.42705274	0.42705274	381.51	0.0001
SUIT(SUBJ*RH)	9	2.02111817	0.22456869	200.62	0.0001
TIME	9	0.0046	0.00051111	0.46	0.9017
RH*TIME	9	0.01388053	0.00154228	1.38	0.2015
SUIT*TIME	9	0.0246301	0.00273668	2.44	0.0121
RH*SUIT*TIME	9	0.01261803	0.001402	1.25	0.2664

Table 22: Analysis of Variance for Sweat Rate – Leg for Exercise Session (10-30 min.)

Source	DF	Type ISS	Mean Square	F Value	Pr > F
SUBJ	5	1.51466129	0.30293226	76.31	0.0001
RH	1	0.75540385	0.75540385	190.28	0.0001
SUBJ*RH	5	2.64886111	0.52977222	133.45	0.0001
SUIT	1	5.87790242	5.87790242	1480.63	0.0001
RH*SUIT	1	0.63856645	0.63856645	160.85	0.0001
SUIT(SUBJ*RH)	10	5.67097461	0.56709746	142.85	0.0001
TIME	20	14.88693489	0.74434674	187.5	0.0001
RH*TIME	20	0.70880514	0.03544026	8.93	0.0001
SUIT*TIME	20	0.08441593	0.0042208	1.06	0.3866
RH*SUIT*TIME	20	0.05028147	0.00251407	0.63	0.8879

Table 23: Analysis of Variance for Sweat Rate – Leg for Recovery Session (31-40 min.)

Source	DF	Type ISS	Mean Square	F Value	Pr > F
SUBJ	5	0.55943109	0.11188622	171.05	0.0001
RH	1	0.71381647	0.71381647	1091.27	0.0001
SUBJ*RH	5	0.60942853	0.12188571	186.34	0.0001
SUIT	1	0.55802909	0.55802909	853.11	0.0001
RH*SUIT	1	0.19407941	0.19407941	296.71	0.0001
SUIT(SUBJ*RH)	9	1.5011015	0.16678906	254.98	0.0001
TIME	9	0.06681261	0.00742362	11.35	0.0001
RH*TIME	9	0.00369429	0.00041048	0.63	0.7725
SUIT*TIME	9	0.07887057	0.0087634	13.4	0.0001
RH*SUIT*TIME	9	0.00213887	0.00023765	0.36	0.951

Table 24: Analysis of Variance for RPE

Source	DF	Type I SS	Mean Square	F Value	Pr > F
SUBJ	5	307.4208333	61.48416667	71.59	0.0001
RH	1	1.50416667	1.50416667	1.75	0.1874
SUIT	1	17.60416667	17.60416667	20.5	0.0001
RH*SUIT	1	0.3375	0.3375	0.39	0.5315
SUBJ*RH*SUIT	15	56.82916667	3.78861111	4.41	0.0001
TIME	9	1421.870833	157.9856482	183.96	0.0001
RH*TIME	9	6.5375	0.72638889	0.85	0.5749
SUIT*TIME	9	38.27083333	4.25231481	4.95	0.0001
RH*SUIT*TIME	9	6.0375	0.67083333	0.78	0.6341

Table 25: Analysis of Variance for Comfort - Absorbent

Source	DF	Type ISS	Mean Square	F Value	Pr > F
SUBJ	5	43.22222222	8.64444444	20.83	0.0001
RH	1	0.44444444	0.44444444	1.07	0.3032
SUIT	1	2.25	2.25	5.42	0.0219
RH*SUIT	1	0.02777778	0.02777778	0.07	0.7964
SUBJ*RH*SUIT	15	15.27777778	1.01851852	2.45	0.0043
TIME	5	6.05555556	1.21111111	2.92	0.0168
RH*TIME	5	1.38888889	0.27777778	0.67	0.6476
SUIT* TIME	5	5.41666667	1.08333333	2.61	0.0291
RH*SUIT*TIME	5	1.63888889	0.32777778	0.79	0.5594

Table 26: Analysis of Variance for Comfort-Breathable

Source	DF	Type I SS	Mean Square	F Value	Pr > F
SUBJ	5	37.88888889	7.57777778	19.85	0.0001
RH	1	1.36111111	1.36111111	3.57	0.0619
SUIT	1	8.02777778	8.02777778	21.03	0.0001
RH*SUIT	1	0	0	0	1
SUBJ*RH*SUIT	15	11.61111111	0.77407407	2.03	0.0202
TIME	5	26.22222222	5.24444444	13.74	0.0001
RH*TIME	5	1.80555556	0.36111111	0.95	0.4548
SUIT*TIME	5	2.63888889	0.52777778	1.38	0.2371
RH*SUIT*TIME	5	3.16666667	0.63333333	1.66	0.1514

Table 27: Analysis of Variance for Comfort - Clammy

Source	DF	Type I SS	Mean Square	F Value	Pr > F
SUBJ	5	80.13888889	16.02777778	31.67	0.0001
RH	1	0.11111111	0.11111111	0.22	0.6404
SUIT	1	10.02777778	10.02777778	19.81	0.0001
RH*SUIT	1	0.02777778	0.02777778	0.05	0.8153
SUBJ*RH*SUIT	15	16.58333333	1.10555556	2.18	0.0115
TIME	5	73.63888889	14.72777778	29.1	0.0001
RH*TIME	5	0.97222222	0.19444444	0.38	0.8586
RH*SUIT	5	2.22222222	0.44444444	0.88	0.4987
RH*SUIT*TIME	5	1.22222222	0.24444444	0.48	0.7882

Table 28: Analysis of Variance for Comfort - Clingy

Source	DF	Type ISS	Mean Square	F Value	Pr> F
SUBJ	5	32.89583333	6.57916667	13.14	0.0001
RH	1	0.00694444	0.00694444	0.01	0.9065
SUIT	1	0.17361111	0.17361111	0.35	0.5573
RH*SUIT	1	0.00694444	0.00694444	0.01	0.9065
SUBJ*RH*SUIT	15	5.85416667	0.39027778	0.78	0.6973
TIME	5	54.0625	10.8125	21.59	0.0001
RH*TIME	5	1.78472222	0.35694444	0.71	0.6153
SUIT*TIME	5	0.61805556	0.12361111	0.25	0.9405
RH*SUIT*TIME	5	1.95138889	0.39027778	0.78	0.5669

Table 29: Analysis of Variance for Comfort - Comfortable

Source	DF	Type ISS	Mean Square	F Value	Pr > F
SUBJ	5	82.64583333	16.52916667	47.95	0.0001
RH	1	0.0625	0.0625	0.18	0.6712
SUIT	1	2.50694444	2.50694444	7.27	0.0082
RH*SUIT	1	0.00694444	0.00694444	0.02	0.8874
SUBJ*RH*SUIT	15	8.71527778	0.58101852	1.69	0.0658
TIME	5	28.22916667	5.64583333	16.38	0.0001
RH*TIME	5	1.0625	0.2125	0.62	0.6875
SUIT*TIME	5	1.78472222	0.35694444	1.04	0.4011
RH*SUIT*TIME	5	0.95138889	0.19027778	0.55	0.7365

Table 30: Analysis of Variance for Comfort - Constricting

Source	DF	Type ISS	Mean Square	F Value	Pr > F
SUBJ	5	26.41666667	5.28333333	12.21	0.0001
RH	1	0.02777778	0.02777778	0.06	0.8005
SUIT	1	1	1	2.31	0.1316
RH*SUIT	1	0	0	0	1
SUBJ*RH*SUIT	15	5.97222222	0.39814815	0.92	0.5448
TIME	5	23.33333333	4.66666667	10.78	0.0001
RH*TIME	5	0.38888889	0.07777778	0.18	0.9696
SUIT*TIME	5	4.91666667	0.98333333	2.27	0.053
RH*SUIT*TIME	5	2.41666667	0.48333333	1.12	0.3564

Table 31: Analysis of Variance for Comfort - Damp

Source	DF	Type ISS	Mean Square	F Value	Pr > F
SUBJ	5	20.36805556	4.07361111	5.95	0.0001
RH	1	0.5625	0.5625	0.82	0.3667
SUIT	1	2.00694444	2.00694444	2.93	0.0899
RH*SUIT	1	0.17361111	0.17361111	0.25	0.6156
SUBJ*RH*SUIT	15	12.04861111	0.80324074	1.17	0.3043
TIME	5	169.1180556	33.82361111	49.44	0.0001
RH*TIME	5	2.39583333	0.47916667	0.7	0.6244
SUIT*TIME	5	3.61805556	0.72361111	1.06	0.3885
RH*SUIT*TIME	5	0.61805556	0.12361111	0.18	0.9693

Table 32: Analysis of Variance for Comfort - Dry

Source	DF	Type ISS	Mean Square	F Value	Pr > F
SUBJ	5	42.39583333	8.47916667	15.25	0.0001
RH	1	0.17361111	0.17361111	0.31	0.5775
SUIT	1	0.34027778	0.34027778	0.61	0.4358
RH*SUIT	1	0.84027778	0.84027778	1.51	0.2218
SUBJ*RH*SUIT	15	17.52083333	1.16805556	2.1	0.0155
TIME	5	149.7291667	29.94583333	53.88	0.0001
RH*TIME	5	4.78472222	0.95694444	1.72	0.1365
SUIT*TIME	5	8.78472222	1.75694444	3.16	0.0108
RH*SUIT*TIME	5	1.28472222	0.25694444	0.46	0.8035

Table 33: Analysis of Variance for Comfort - Flexible

Source	DF	Type ISS	Mean Square	F Value	Pr > F
SUBJ	5	43.70138889	8.74027778	22.69	0.0001
RH	1	0.17361111	0.17361111	0.45	0.5036
SUIT	1	0.84027778	0.84027778	2.18	0.1429
RH*SUIT	1	2.00694444	2.00694444	5.21	0.0246
SUBJ*RH*SUIT	15	9.9375	0.6625	1.72	0.0588
TIME	5	28.20138889	5.64027778	14.64	0.0001
RH*TIME	5	0.70138889	0.14027778	0.36	0.872
SUIT*TIME	5	2.03472222	0.40694444	1.06	0.3893
RH*SUIT*TIME	5	0.70138889	0.14027778	0.36	0.872

Table 34: Analysis of Variance for Comfort - Heavy

Source	DF	Type ISS	Mean Square	F Value	Pr> F
SUBJ	5	40.47222222	8.09444444	21.71	0.0001
RH	1	0.11111111	0.11111111	0.3	0.5863
SUIT	1	3.36111111	3.36111111	9.02	0.0034
RH*SUIT	1	0.44444444	0.44444444	1.19	0.2775
SUBJ*RH*SUIT	15	4.91666667	0.32777778	0.88	0.5888
TIME	5	22.72222222	4.54444444	12.19	0.0001
RH*TIME	5	0.63888889	0.12777778	0.34	0.8858
SUIT*TIME	5	0.55555556	0.11111111	0.3	0.9129
RH*SUIT*TIME	5	0.80555556	0.16111111	0.43	0.8252

Table 35: Analysis of Variance for Comfort - Hot

Source	DF	Type ISS	Mean Square	F Value	Pr > F
SUBJ	5	36.33333333	7.26666667	15.05	0.0001
RH	1	1	1	2.07	0.1532
SUIT	1	4	4	8.29	0.0049
RH*SUIT	1	0.02777778	0.02777778	0.06	0.8109
SUBJ*RH*SUIT	15	9.72222222	0.64814815	1.34	0.1917
TIME	5	79.08333333	15.81666667	32.76	0.0001
RH*TIME	5	1.33333333	0.26666667	0.55	0.7362
SUIT*TIME	5	3.66666667	0.73333333	1.52	0.1906
RH*SUIT*TIME	5	2.30555556	0.46111111	0.96	0.4491

Table 36: Analysis of Variance for Comfort - Snug

Source	DF	Type ISS	Mean Square	F Value	Pr > F
SUBJ	5	44.03472222	8.80694444	33.13	0.0001
RH	1	0.00694444	0.00694444	0.03	0.8719
SUIT	1	0.5625	0.5625	2.12	0.1489
RH*SUIT	1	0.34027778	0.34027778	1.28	0.2606
SUBJ*RH*SUIT	15	10.54861111	0.70324074	2.65	0.0021
TIME	5	14.28472222	2.85694444	10.75	0.0001
RH*TIME	5	0.28472222	0.05694444	0.21	0.9558
SUIT*TIME	5	1.5625	0.3125	1.18	0.3266
RH*SUIT*TIME	5	0.78472222	0.15694444	0.59	0.7073

Table 37: Analysis of Variance for Comfort - Stiff

Source	DF	Type ISS	Mean Square	F Value	Pr > F
SUBJ	5	38.5625	7.7125	21.91	0.0001
RH	1	0.5625	0.5625	1.6	0.2091
SUIT	1	0.0625	0.0625	0.18	0.6744
RH*SUIT	1	0.00694444	0.00694444	0.02	0.8886
SUBJ*RH*SUIT	15	19.07638889	1.27175926	3.61	0.0001
TIME	5	6.39583333	1.27916667	3.63	0.0046
RH*TIME	5	1.72916667	0.34583333	0.98	0.4323
SUIT*TIME	5	2.72916667	0.54583333	1.55	0.181
RH*SUIT*TIME	5	1.11805556	0.22361111	0.64	0.6732

Table 38: Analysis of Variance for Comfort - Thick

Source	DF	Type ISS	Mean Square	F Value	Pr > F
SUBJ	5	101.4722222	20.29444444	56.64	0.0001
RH	1	0.44444444	0.44444444	1.24	0.2681
SUIT	1	0.25	0.25	0.7	0.4056
RH*SUIT	1	0.02777778	0.02777778	0.08	0.7813
SUBJ*RH*SUIT	15	15.69444444	1.0462963	2.92	0.0007
TIME	5	15.30555556	3.06111111	8.54	0.0001
RH*TIME	5	1.80555556	0.36111111	1.01	0.4172
SUIT*TIME	5	1.16666667	0.23333333	0.65	0.6613
RH*SUIT*TIME	5	2.55555556	0.51111111	1.43	0.2213

Table 39: Analysis of Variance for Comfort - Warm

Source	DF	Type ISS	Mean Square	F Value	Pr > F
SUBJ	5	10.72916667	2.14583333	3.65	0.0045
RH	1	0.17361111	0.17361111	0.3	0.5881
SUIT	1	0.17361111	0.17361111	0.3	0.5881
RH*SUIT	1	0.5625	0.5625	0.96	0.3304
SUBJ*RH*SUIT	15	6.29861111	0.41990741	0.71	0.7651
TIME	5	67.22916667	13.44583333	22.86	0.0001
RH*TIME	5	0.61805556	0.12361111	0.21	0.9575
SUIT*TIME	5	2.78472222	0.55694444	0.95	0.4542
RH*SUIT*TIME	5	1.0625	0.2125	0.36	0.8738

Table 40: Analysis of Variance for Comfort - Wet

Source	DF	Type ISS	Mean Square	F Value	Pr > F
SUBJ	5	64.30555556	12.86111111	30.18	0.0001
RH	1	0.44444444	0.44444444	1.04	0.3096
SUIT	1	0.69444444	0.69444444	1.63	0.2047
RH*SUIT	1	0.02777778	0.02777778	0.07	0.799
SUBJ*RH*SUIT	15	10.08333333	0.67222222	1.58	0.0935
TIME	5	172.1388889	34.42777778	80.8	0.0001
RH*TIME	5	1.30555556	0.26111111	0.61	0.6903
SUIT*TIME	5	0.72222222	0.14444444	0.34	0.8882
RH*SUIT*TIME	5	1.22222222	0.24444444	0.57	0.72

VITA

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