INFLUENCE OF FABRIC ON THRESHOLD DETERMINATIONS FOR MOISTURE SENSATION

By

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SENSATION

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CHAPTER I

INTRODUCTION

Background

The concept of comfort is most interesting, but many do not agree on its definition due to its complexity. Clothing comfort has recently been defined as "a state of satisfaction indicating physiological, psychological and physical balance among the person, his/her clothing, and his/her environment" (Branson & Sweeney, 1987, p. 14). Comfort is dynamic and ever-changing, dependent on such things as the environment, emotions, fabric structure, fiber type, or moisture content--just to name a few.

Psychological scaling techniques are quite often used to assess comfort because a subject can recognize and rate the sensation after exposure to extreme or varying environmental conditions and/or levels of activity. Many different scales have been developed to measure general comfort, thermal sensations, and humidity or wetness sensations. But when the results of these studies are compared, the scales used yield different results signifying that they do not measure sensations similarly (Lavinia & Rohles, 1987; Gagge, Stolwijk, & Hardy, 1967).

The body is constantly trying to maintain body temperature for heat balance. A skin temperature of about 34° C and core body temperature of 37° C is considered a thermally comfortable state (Hardy, 1968). Clothing acts as a barrier in the thermoregulatory process, protecting the body from the environment. Heat exchange must occur through clothing to ensure proper balance with the environment (Mecheels & Umbach, 1977; DeMartino, Yoon, Buckley, Evins, Averell, Jackson, Schultz, Becker, Booker, & Hollies, 1984).

A major physical factor that influences clothing comfort is the movement of water through fabric (Slater, 1977; Mehta & Narrasimham, 1987). The way in which moisture is handled by fabric at the skin interface is very important (Hollies, 1965). Experiments indicate that subjects are able to perceive moisture in fabric, yet there are no known special skin receptors to detect wetness sensations (Hollies, 1977; Sweeney, 1988; Vokac, Kopke, & Keul, 1976; Holmer, 1985).

Generally as moisture content of clothing increases, comfort ratings decrease. A very small amount of moisture can affect comfort ratings when skin is interfaced with fabric (Hollies, 1965; Hollies, 1971; Scheurell, Spivak, & Hollies, 1985). The contact sensation may change when wet fabric lies against the skin causing friction/adhesion when fabric is moved (Yamakawa & Isaji, 1987; Gwosdow, Stevens, Berglund, & Stolwijk, 1986).

Evaporation of sweat from the skin's surface is the

body's most efficient way to cool itself. The strateum corneum (SC) is the outside layer of skin and consists of epidermal cells. It serves as another environmental barrier for the body in addition to clothing, by controlling water passage through the skin (Hatch, Wilson, & Maibach, 1987).

> Changes in relative humidity alter water content and evaporation in a complex manner. The relationship is nonlinear, with skin water evaporation decreasing as relative humidity increases (Hatch et al, 1987, p. 584).

The ability of a fabric to transport moisture from (and into) the skin/clothing interface is very important for comfort acceptability (Hollies, 1977). A fabric transports moisture in either a liquid or vapor phase. Mass liquid moisture transport occurs through fabric or along the plane of the fabric and is known as wicking. However, wicking rarely occurs during actual wear because garments do not usually get completely wet (Hong, Hollies, & Spivak, 1988). The other method of moisture transport is moisture vapor permeability and it is the most common way for moisture to be transported through fabric (Hollies, 1977). Vapor passage occurs most often through the air spaces of the fabric (Wehner, Miller, & Rebenfeld, 1988; Mehta & Narrasimham, 1987).

Theoretical Framework

The theoretical framework for this study is provided by the scientific study of psychophysics, which measures the physical stimulus in relation to the resulting psychological

sensation. Sensory research is based on this foundation and since clothing comfort is a "felt" sensation in response to a physical stimulus (like wetness), the psychophysical approach is justified.

Psychophysics can quantitatively assess the relationship between physical stimuli and psychological sensations. The physical continuum is easily measurable (temperature, moisture content) while the psychological continuum may be more difficult to assess (comfort, wetness, pleasantness). The relationship between the two continua depends on "the complete sequence of events in any psychophysical determination:

Stimulus ---> Sensation ---> Judgmental Response" (D'Amato, 1970, p. 120).

Purpose

The purpose of this study was to use the psychophysical method of constant stimuli to investigate moisture sensation as it relates to fabric characteristics. The hand was chosen as the test site because when wearing athletic/sport gloves (raquetball, baseball, weightlifting) or protective-type gloves (pesticide or chemically protective) there may be an impairment of performance, such as decreased dexterity or a weakened/slipping grip, due to moisture on the hand, in the glove, or at the hand/glove interface.

Objectives

1. This study used the psychophysical method of constant stimuli to determine the absolute and difference thresholds for moisture sensation in one body area using four selected fabrics. The back/top of the hand was the chosen body site because a glove would likely make contact with the skin in this area.
2. To explore how fabric characteristics influenced threshold determinations.

Hypotheses

Ho_1: There will be no significant difference in absolute thresholds by fabric.

Ho_2: There will be no significant difference in difference thresholds by fabric.

Definitions

Thermal Comfort

Thermal comfort is a condition of mind which expresses satisfaction with the thermal environment (ASHRAE, 1981).

Psychophysics

Psychophysics is the scientific study of the relationship between the stimuli in the physical domain and the sensations in the psychological domain (Gescheider, 1976).

Absolute Threshold

The absolute threshold is the minimum value of a physical stimulus that will evoke a sensation. Operationally defined it is the stimulus value that is detected 50% of the time (Gescheider, 1976).

Difference Threshold

The difference threshold is the minimum amount of physical stimulus change required to produce a sensation difference. Variable stimulus values are judged "less" or "greater" than a standard stimulus 25 and 75 percent of the time, and are averaged to give the difference threshold (Gesheider, 1976).

Condensation

The phase change of moisture from vapor to liquid (Webster's New Collegiate Dictionary, 1976).

Evaporation

The phase change of moisture from liquid to vapor (Webster's New Collegiate Dictionary, 1976).

Distillation

An important means of diffusional passage for moisture in clothing systems. Moisture starts as vapor that is evaporated from the skin, condenses on fabric surfaces, redistributes throughout the fabric, and then reevaporates to the environment (Hong, 1985).

Sorption

The process of taking up and holding by either adsorption or absorbtion (Webster's New Collegiate Dictionary, 1976).

Flux

The rate of moisture vapor transmission (Hong, 1985).

CHAPTER II

LITERATURE REVIEW

This chapter is organized into six major subdivisions. The first section introduces comfort terminology, distinguishes types of comfort as they relate to clothing, and discusses comfort measuring techniques. The next two sections focus on clothing and skin respectively. Moisture transport through fabrics and/or clothing is covered in section four. The last two sections review psychophysics and psychophysical methods.

Comfort Terminology and Measurement

The concept of comfort is most interesting, but there is no standard definition on which everyone agrees. General comfort has been defined as "a pleasant state of physiological, psychological, and physical harmony between a human being and the environment" (Slater, 1985, p. 4). Other definitions describe general comfort as a state of well-being or neutral sensation (Sontag, 1985-1986; Mehta & Narrasimham, 1987).

Thermal Comfort

Thermal comfort is defined by the American Society of

Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) as "the condition of mind which expresses satisfaction with the thermal environment (1981, p. 2). This definition suggests that a perceptual assessment takes place, that a person feels or senses something (like wetness or temperature) and can make a value judgment regarding those feelings or sensations (Rohles, 1971). In addition, thermal comfort is dynamic. An individual's assessment of their thermal comfort may change over time depending on the environmental conditions, clothing worn, behavioral activity, and even emotions.

Thermal comfort can be thought of as having three influential components: the person, the clothing, and the environment. Fourt and Hollies (1970) view these components as a triad striking a "balance between body and environment that is modified by the intervention of clothing" (p. 1). Though thermal comfort is very important to clothing comfort, it is believed that there may be other factors involved in judgmental responses of clothing comfort. For example, the sound of parts of a raincoat rubbing against each other may be irritating to the wearer and lead to a judgment of clothing discomfort.

Clothing Comfort

To better understand comfort as it applies to the person and clothing, researchers have proposed some clothing comfort models. One model termed "Comfort's Gestalt",

developed by Pontrelli (1977), involves both physical and psycho-physical stimuli filtering through a screen of stored modifiers (Fig. 1). The purpose of this model is to "establish the comfort concept as a subjective response to stimuli and not as an inherent property of fibers, fabrics, or garments" (Branson & Sweeney, 1987). Pontrelli used the term "gestalt" in the model's title to demonstrate that a comfort judgment does not come from physical, psychological, and physiological stimuli assessments alone, but from the interaction between them and the stored modifiers of each individual person. A major criticism of this model is that the names/labels of the two major input categories are unclear and do not apply accurately to the variables within (Branson & Sweeney, 1987).

Sontag (1985-1986) developed a human comfort model directed toward comfort perception and behavioral response with the triad in three concentric circles labeled person, clothing, and environmental attributes (Fig. 2). This model includes the stored modifiers from Pontrelli's (1977) model in the inner circle of person attributes. The arrow labeled "perception/response" running through all three circles represents the balance a person seeks between how they are perceived by others in the environment and their own perception of themself. When the two perceptions are unequal a person responds by becoming more comfortable or less uncomfortable (Branson & Sweeney, 1987).

Sontag's approach to human comfort is an ecological one

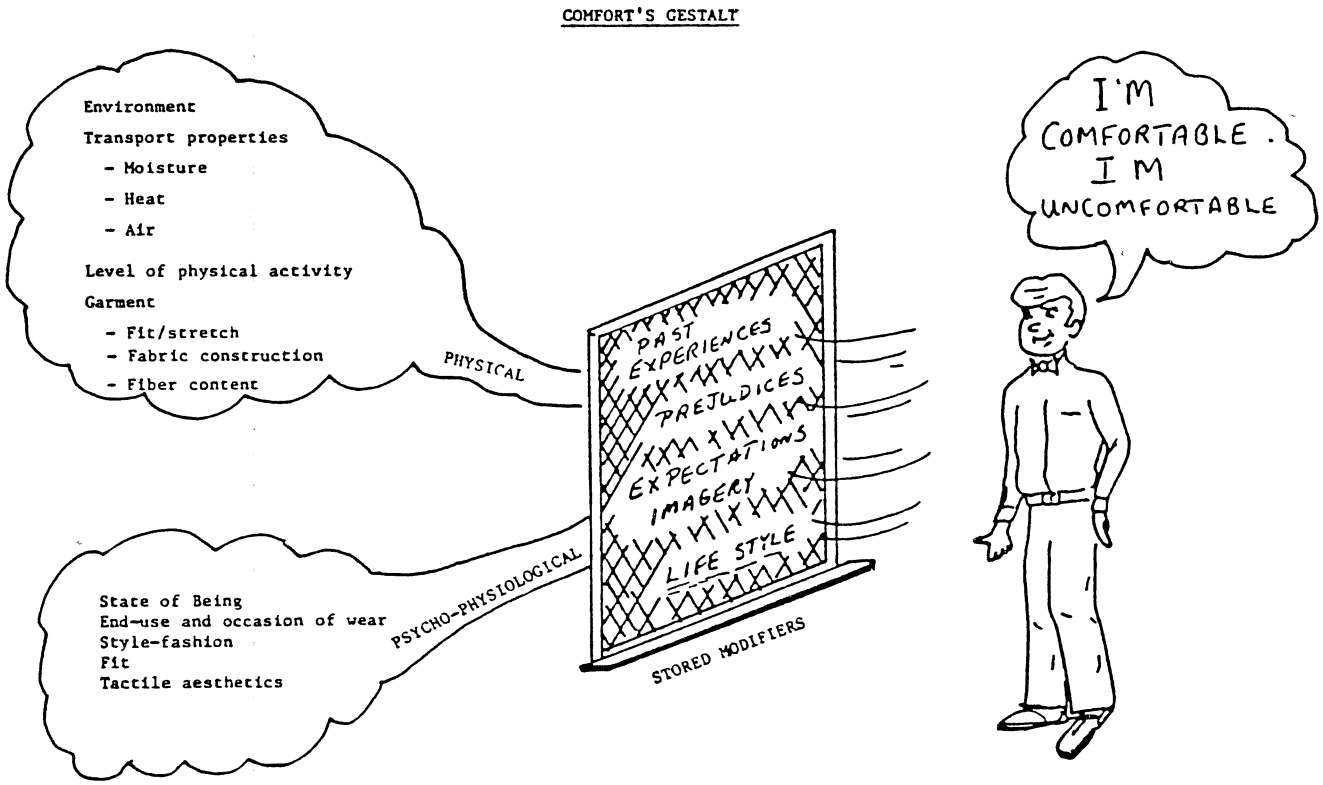

Figure 1. Comfort's Gestalt. From"Partial Analysis of Comfort's Gestalt" (p.72) by G. J. Pontrelli, 1977. In N. R. S. Hollies & R. F. Goldman (Eds.), Clothing Comfort, Ann Arbor, MI: Ann Arbor Science. Copyright by Ann Arbor Science.

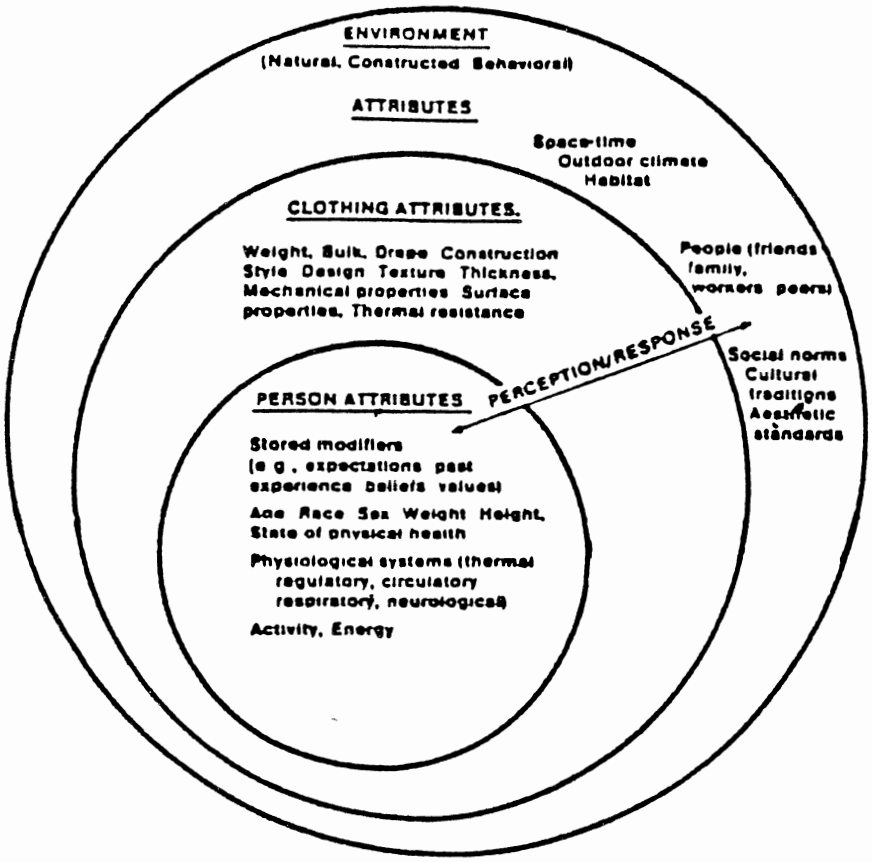

Figure 2. Attributes of the Triad (person, clothing, environment). Influential in Comfort Perception and Behavioral Response. From "Comfort Dimensions of Actual and Ideal Insulative Clothing for Older Women" by M. S. Sontag, 1985-1986, Clothing and Textiles Research Journal, 4, p. 16. Reprinted with permission.

with three dimensions of comfort: physical, psychological, and social. While the author defines these dimensions as they apply to clothing comfort, the model was not proposed solely for that particular purpose and when the model was tested, data did not support a differentiation between the psychological and social comfort dimensions (Sontag, 1985-1986).

The most recent clothing comfort model was proposed by Branson and Sweeney (1987) in a position paper presented to the Association of College Professors of Textiles and Clothing (Fig. 3). This ordered model proposes that the triad elements of person, clothing, and environment each have physical and psychological dimensions that can influence the resulting response and judgment. Attributes in the physical dimension are easily measurable like age of a person, fiber content of clothing, and air temperature of the environment. Psychological attributes are very important and harder to assess, but may include one's self-concept, style of clothing, and the social norms of the environment. These attributes interact within each dimension and across dimensions to produce physiological/perceptual responses like skin temperature, sweat rate, and moisture or temperature sensations. The processing of these responses occurs in the mind in the form of Pontrelli's (1977) filtering component and the comfort judgment results. The judgment will not always be the same because a garment considered comfortable at one time may be

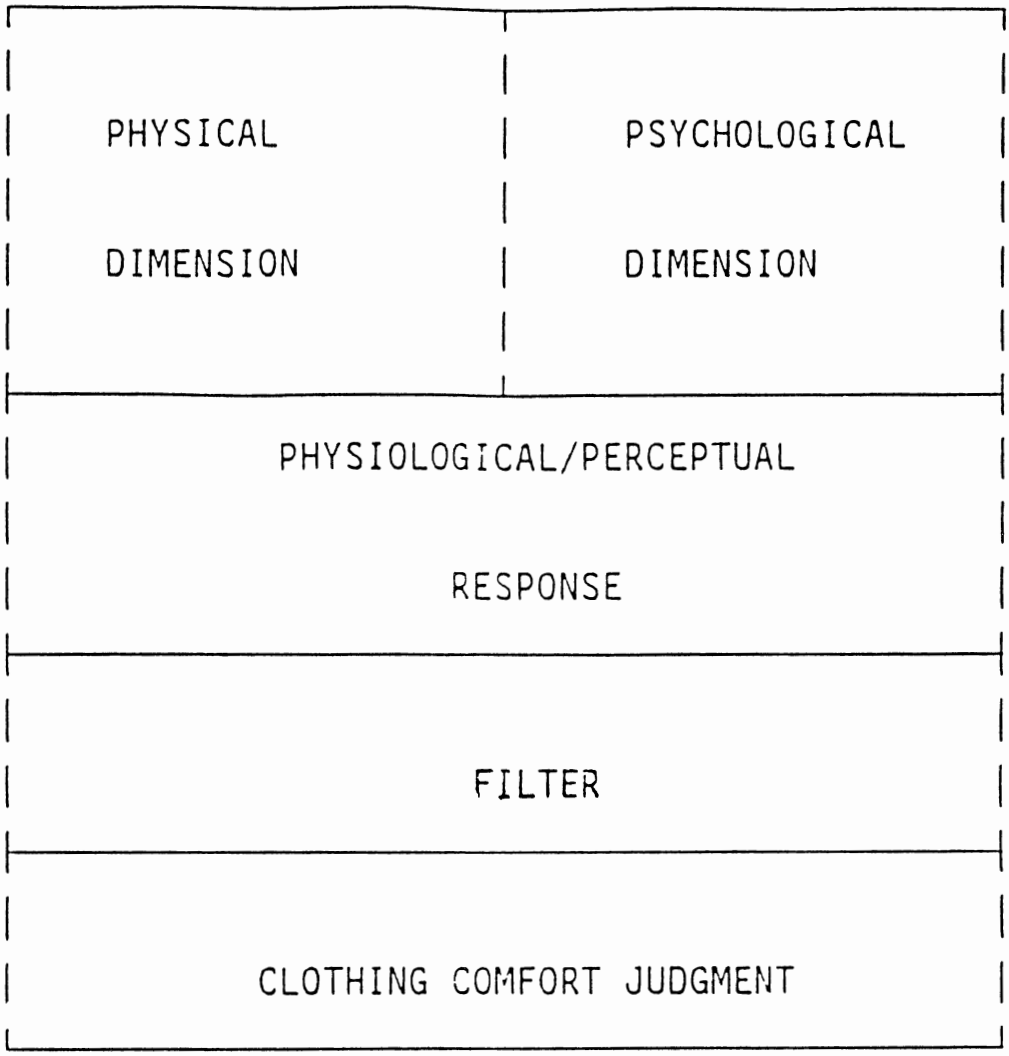

Figure 3. Proposed Clothing Comfort Model. From "Clothing Comfort Conceptualization and Measurement: Toward a Metatheory" (p. 18) by D. H. Branson and M. Sweeney, 1987. Paper presented at ACPTC annual meeting, Dearborn, MI. Reprinted with permission.

judged uncomfortable another time (Branson & Sweeney, 1987).

Clothing comfort is defined by Branson and Sweeney (1987) as "the state of satisfaction indicating physiological, psychological, and physical balance among the person, his/her clothing, and his/her environment" (p. 14). Clothing comfort has two major subdivisions, sensorial clothing comfort and thermal comfort.

Sensorial clothing comfort is "a state of satisfaction with how a fabric or garment is perceived by the senses of the wearer" (Branson & Sweeney, 1987, p. 15). Examples of what is meant by sensorial clothing comfort include perceptions of fabric/clothing smell, sound, and/or touch (Comfort in casuals, 1985). Thermal comfort, seen as a subset of both clothing and sensorial comfort, may include perceptions of the thermal environment.

Thermal Comfort/Thermal Sensation Measurements

"The process of making judgments from our sensory perception of the world is termed psychological scaling" (Sweeney, 1988). These scaling techniques are used to measure individuals' feelings or responses toward their environment (Rohles, Konz, McCullough, & Millikin, 1983). Comfort scaling consists of a subject recognizing a sensation, or multiple combined sensations, and rating it/them. The literature shows that there have been numerous studies conducted to assess the subjective aspect of comfort sensations using psychological scales, most focusing on

those sensations dealing with thermal or temperature perception, general comfort, and clothing/skin interface.

Yaglou (1927) was one of the first researchers to use a psychophysical scale in the description of a thermal environment. Participating subjects were exposed to varying ambient temperatures and relative humidities and asked to describe their state on a five-point response scale from cold to too warm. Winslow, Herrington, and Gagge (1937) also used a five-point response scale with the terms very pleasant to very unpleasant. This scale deliberately used the term "pleasant" in an attempt to avoid reference to thermal sensations (cold or hot).

Many thermal comfort/sensation scales are based on seven or nine points with the thermal comfort sensation operationally defined to fall within that range. A seven-point scale from cold to hot, originally developed by Houghton and Yaglou (1923), was modified by changing the term "comfortable" to "neutral" and compared to Winslow's pleasant scale and a four-point comfort sensation scale (Fig. 4) by Gagge, Stolwijk, and Hardy (1967). This scale comparison was done in an attempt to see if subjects would rate their sensations the same on all three scales. Results from this study and others indicate that the different scales prompted dissimilar sensations from subjects, demonstrating their inequality (Vokac, Kopke, & Keul, 1976; Holmer, 1985; Morooka & Niwa, 1979).

The McGinniss Thermal Scale (Fig. 5) is a lineasr scale

Scale of comfort sensation	Scale of thermal sensation
1. Comfortable	1, Cold
2. Slightly uncomfortable	2. Cool
3. Uncomfortable	3. Slightly cool
4, Very uncomfortable	4. Neutral
	5, Slightly warm
	6, Warm
	7, Hot

Figure 4. Category Scales for Comfort and Temperature Sensation. From "Comfort and Thermal Sensations and Associated Physiological Responses at Various Ambient Temperatures" by A. P. Gagge, J. A. J. Stolwijk, and J. D. Hardy, 1967, Environmental Research, 1, p. 3. Copyright 1967 by Academic Press, Inc. Reprinted with permission.

I AM:

1. So cold I am helpless
2. Numb with cold
3. Very cold
4. Cold
5. Uncomfortably cool
6. Cool but fairly comfortable
7. Comfortable
8. Warm but fairly comfortable
9. Uncomfortably warm
10. Hot
11. Very hot
12. Almost as hot as I can stand
13. So hot I am sick and nauseated

Figure 5. McGinniss Thermal Scale. From "A Human Perception Analysis Approach to Clothing Comfort" by N. R. S. Hollies, A. G. Custer, C. J. Moran, and M. E. Howard, 1979, Textile Research Journal, 49, p. 559. Copyright 1979 by the Textile Research Institute. Reprinted with permission.

that was developed by Hollies (1977) to be used in both hot and cold environments for thermal stress assessment. Recently, the McGinniss Scale has been used by Hollies, Custer, Morin, and Howard (1979) and DeMartino, Yoon, Buckley, Evins, Averell, Jackson, Schultz, Becker, Booker, and Hollies (1984) to assess metabolic pre-conditioning of subjects and the repeatability of the microclimate-conditioning protocol.

In the specialized area of protective clothing, thermal comfort is very important for human acceptability reasons. Branson, DeJonge, and Munson (1986) used a nine point scale from very hot to very cold, developed by Rohles, Millikin, and Kristic (1979) to assess thermal sensation under given test conditions. In addition, a thermal comfort assessment using a semantic differential scale with eight bipolar adjective pairs separated by nine spaces, developed by Rohles et al. (1983) was used to further improve the knowledge of comfort scaling techniques for protective clothing.

Still another approach for subjectively evaluating thermal comfort, developed by Lavinia and Rohles (1987) compares a six pair bipolar adjective thermal comfort ballot to a 32-item differential attribute ballot (Figs. 6 and 7). For this multiple item ballot the rater must evaluate each descriptor with a seven point scale from very accurate to very inaccurate. Two separate rating scales were generated from these two ballots, thermal satisfaction and

COMFORTABLE	___:	___:	___:	___:	___:	___:	___:	___:	___	UNCOMFORTABLE
BAD TEMPERATURE	___:	___:	___:	___:	___:	___:	___:	___:	___	GOOD TEMPERATURE
PLEASANT	___:	___:	___:	___:	___:	___:	___:	___:	___	UNPLEASANT
UNACCEPTABLE	___:	___:	___:	___:	___:	___:	___:	___:	___	ACCEPTABLE
SATISFIED	___:	___:	___:	___:	___:	___:	___:	___:	___:	DISSATISFIED
UNCOMFORTABLE TEMPERATURE	___:	___:	___:	___:	___:	___:	___:	___:	___	COMFORTABLE TEMPERATURE

Figure 6. Thermal Comfort Scale in Semantic Differential Format. From "Thermal Comfort: A New Approach for Subjective Evaluation" by J. E. Lavinia and R. H. Rohles, 1987, ASHRAE Transactions, 93(1), p. 1077. Copyright 1987 by the American Society for Heating, Refrigerating and Air Conditioning Engineers.

THERMAL ENVIRONMENT BALLOT

Instructions: Below is a list of words that can be used to describe the thermal environment. We would like you to rate how accurately the words below describe the THERMAL ENVIRONMENT of this place. Use the following 1-7 scale for your answer for each word.

7 = very accurate
6 = accurate
5 = slightly accurate
4 = NEUTRAL, neither accurate nor inaccurate
3 = slightly inaccurate
2 = inaccurate
1 = very inaccurate

THE THERMAL ENVIRONMENT

1	uncomfortable	_____	12.	good	_____	23	intolerable	_____
2.	content with	_____	13.	unacceptable	_____	24	disagreeable	_____
3	agreeable	_____	14	enjoyable	_____	25	adequate	_____
4	tolerable	_____	15	great	_____	26	desirable	_____
5	unpleasant	_____	16	distressful	_____	27	unsatisfactory	_____
6	inadequate	_____	17	bad	_____	28	gratifying	_____
7	annoying	_____	18	acceptable	_____	29	pleasing	_____
8	undesirable	_____	19	discontent with	_____	30	poor	_____
9	satisfactory	_____	20	pleasant	_____	31	appealing	_____
10.	miserable	_____	21	dissatisfied with	_____	32	delightful	_____
11	satisfied with	_____	22	comfortable	_____			

Figure 7. Thermal Environment Ballot. From "Thermal Comfort: A New Approach for Subjective Evaluation" by J. E. Lavinia and R. H. Rohles, 1987, ASHRAE Transactions, 93(1), p. 1078. Copyright 1987 by the American Society for Heating, Refrigerating and Air Conditioning Engineer.

dissatisfaction. When comparisons between the two were made "the findings suggested that the satisfaction and dissatisfaction scales did not measure the subjective response in the same way as the traditional comfort ballot" (Lavinia & Rohles, 1987, p. 1069). The differences in comfort ratings may have possibly been due to the fact that comfort sensations are affected by many factors other than just thermal considerations.

Clothing

The human body strives to maintain a constant body temperature which is critical to normal bodily functions. Heat production must be equal to heat loss for a person to be in heat balance (Guyton, 1986). If an imbalance occurs the body's thermoregulatory mechanisms may be initiated to produce or dissipate heat by one or a combination of the physiological methods of heat exchange including conduction, convection, evaporation, radiation, sweating, and shivering, and/or behavioral type actions such as increased exercise or crossing the arms or legs.

Clothing plays a part in some of these methods of heat exchange because the exchange occurs through the clothing ensemble itself, thus interacting with the thermoregulatory system of the body (Mecheels & Umbach, 1977). One purpose of clothing is to sustain a constant body temperature which has been shown to be a vital factor in deciding comfort (DeMartino et al., 1984). A mean skin temperature of about

33-35 C and core temperature of 37 C is considered a thermally comfortable state when temperature regulation is totally vasomotor controlled (Hardy, 1968).

> The best clothing system enables the body's thermoregulation under subjectively felt comfort conditions to control the broadest range of different climatic conditions and different work loads. This is termed the psychometric range of a clothing system (Mecheels & Umbach, 1977, p. 134).

It is generally agreed that the major physical factors that influence clothing comfort are the movement of heat, moisture, and air through fabric (Slater, 1977; Mehta & Narrasimham, 1987). The capability of clothing to handle moisture at the skin interface and the nature of that contact can greatly influence clothing comfort sensations (Hollies, 1965).

The determination of moisture in clothing has been limited in the past to subjective scales. Hollies (1977) used a four point scale with the terms dry, slightly damp, moderately damp, and wet to assess wetness perceptions of subjects wearing shirts that were treated with a fluorocarbon finish to change their drying rates. Results showed that as water content increased the wearers were accurately able to perceive the increase (Fig. 8). A study conducted with vests of cotton and polypropylene worn in four combinations in a cold environment with periods of intensive walking (to promote sweating), produced similar results as did another study with wool and nylon garments (Vocak et al., 1976; Holmer, 1985).

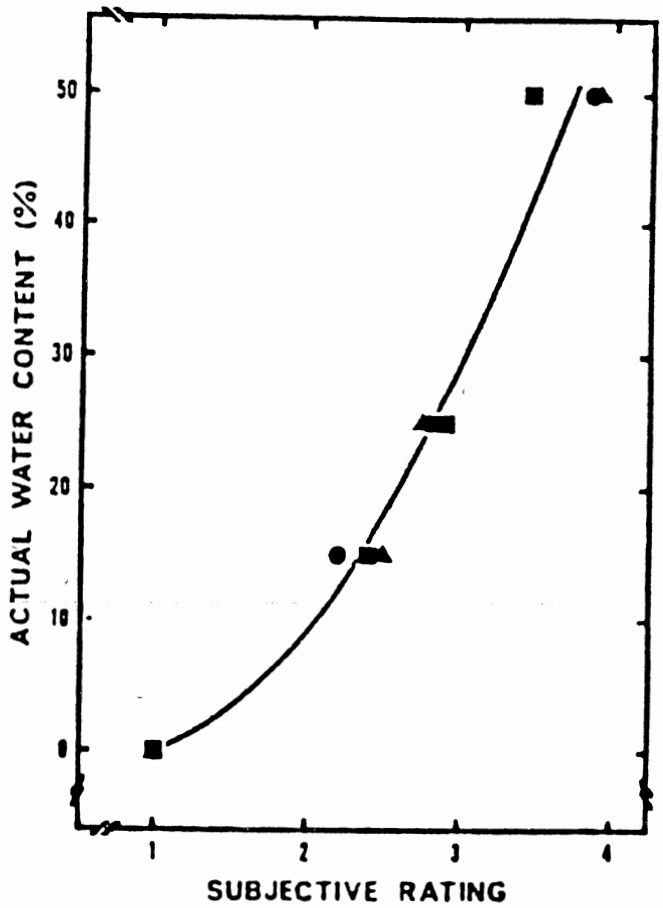

Figure 8. Perception of Moisture in Clothing. From "Psychological Scaling in Comfort Assessment" (p. 115) by N. R. S. Hollies, 1977. In N. R. S. Hollies & R. F. Goldman (Eds.), Clothing Comfort, Ann Arbor, MI: Ann Arbor Science. Copyright by Ann Arbor Science.

Contact sensation may be escalated when sweaty moist skin is interfaced with fabric, even when a very small amount of moisture is involved, causing discomfort (Hollies, 1965; Hollies, 1971). Results indicated a strong relationship between the water content of the clothing due to sweating, the relative humidity, and the subjective comfort rating assigned to the garment worn. As fabric/clothing and environmental moisture increased, the comfort rating of that garment decreased (Hollies, 1971). A similar study by Scheurell, Spivak, and Hollies (1985) indicated discomfort sensations were directly influenced by the amount of moisture at the clothing/skin interface, which resulted in lower comfort ratings of knit shirts after exercising in a hot environment with varying humidity.

Many studies on the tactile perception of clothing, or the actual interface sensation between fabric and skin have asked subjects to use a four point intensity scale to rate descriptive sensations experienced such as clammy, damp, clingy, and sticky after subjects were exposed to exercise and/or changing environmental conditions. Hollies et al. (1979) used cotton and Nomex shirts and cotton and polyester/cotton blend jeans and found a comfort preference for the cotton garments. DeMartino et al. (1984) used long sleeved cowl neck tops of untreated polyester, cotton, and polester/cotton blends and found that the cotton was considered most comfortable and was preferred over the other

fabrics. In a second part of this same study, polyester was modified through engineering, cross-section variation, and pressure jet treatments and showed improved perceived comfort that was equal to or exceeded polyester/cotton blends and all cotton from part one of the study. Under normal wearing conditions when the body's heat balance was held constant and there was no active sweating, the perception of tactile differences was not present except when the fabric was highly textured (Hollies, DeMartino, Yoon, Buckley, Becker, & Jackson, 1984).

Gwosdow, Stevens, Berglund and Stolwijk (1986) conducted research to see if skin wettedness influenced perception of fabric texture and pleasantness. Subjects were exposed to different environmental conditions: neutral, hot-dry, hot-humid, and back to neutral, and had six fabrics varying in texture pulled across their inner forearm and were required to mark their responses on a two-line subjective rating chart (Fig. 9). In general, results showed that skin temperature increased or decreased with the ambient temperature in the chamber and that as skin temperature, skin hydration, and skin wettedness increased, perceived texture increased and fabric pleasantness ratings decreased. Interestingly, all fabrics were reported as most textured in the hot-humid stage of testing. The authors proposed that "skin hydration caused by sweat may have softened the skin's surface, increasing the number of contact points between the skin and fabric" (Gwosdow et al.,

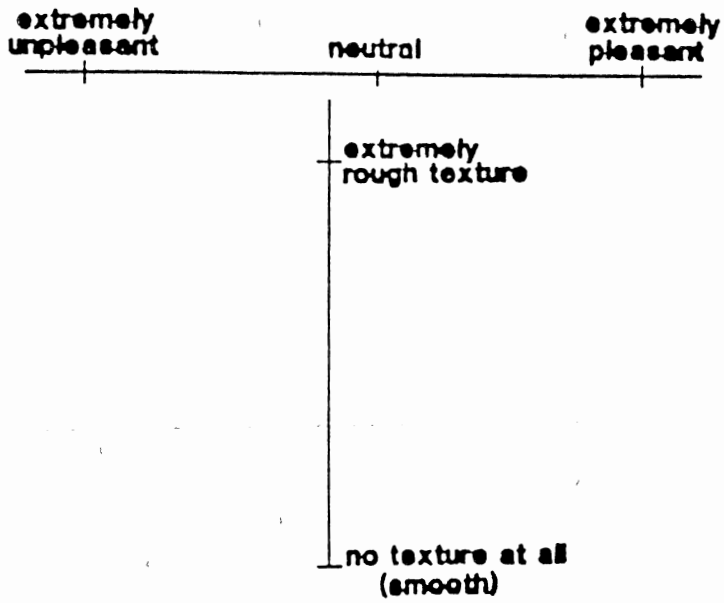

Figure 9. Subjective Rating Chart. From "Skin Friction and Fabric Sensations in Neutral and Warm Environments" by A. R. Gwosdow, J. C. Stevens, L. G. Berglund, and J. A. J. Stolwijk, 1986, Textile Research Journal, 56, p. 575. Copyright by the Textile Research Institute. Reprinted with permission.

1986, p. 578). Moisture on either the fabric or skin can increase the amount of friction/adhesion between them causing more drag (Yamakawa & Isaji, 1987).

Skin

Evaporation of sweat from the skin's surface is an excellent and efficient means of heat dissipation when the body is trying to lose heat possibly due to exercise or hot weather. The conversion of liquid sweat to a vapor state depends on the vapor concentration gradient between the body and ambient air (Jensen, 1980). Sweat glands are the physiological mechanisms controlled by the sympathetic nervous system, that produce sweat when stimulated. The volume of sweat secreted is proportional to the number of nerve impulses received from the brain. If the body is in heat balance, sweat in excess will not be produced, although insensible perspiration occurs continuously in various body parts. A study by Tokura and Midorikawa-Tsuratani (1985) using untreated and hygroscopically treated polyester and cotton found that sweat produced by the body varied by fabric in a warm environment. Sweat rate was measured at the frontal chest level with thermocouples and hygrometer after one hour. In addition, sweat drops were wiped off the skin's surface with a dry towel that was weighed along with the garment ensemble worn.

The region of the skin that touches fabric is the strateum corneum (SC) made up of epidermal cells. The

purpose of the SC is to serve as an environmental barrier for the body and "helps to maintain an optimal hydration state for internal organs by controlling the passage of water" (Hatch, Wilson, & Maibach, 1987, p. 584). A change in the SC water content can be accomplished by occlusive materials and some hand lotions by causing the surface to become more hydrated thereby increasing evaporation.

Transepidermal diffusion varies greatly over the body despite fairly uniform skin thickness, except for the palms and soles of the feet (Rushmer, Buettner, Short, & Odland, 1966). The palm's SC layer is 40 times thicker than the back of the hand and sweats continuously and invisibly even in a cool environment, as do the soles of the feet (Baker & Kligman, 1967; Kuno, 1959).

The amount of relative humidity in the air can change the SC's hydration and evaporative capabilities--as environmental humidity increases evaporation from the skin decreases (Hatch, et al., 1987). Air movement can also alter the hydration of the SC by increasing the rate of evaporation by forced convection, altering the water flux through the skin (Blank, 1952).

In a study done by Hatch, et al. (1987), two different fabrics (some covered with plastic film) were placed on subjects' skin for various time periods. Results showed a statistical difference in SC hydration and evaporation in occluded samples due to fabric type, but no statistical difference in unoccluded samples due to fabric type. The

nondifference in unoccluded samples is possibly attributed to the body's ability to evaporate moisture from the fabrics at conditions of 22^0 C and 55% relative humidity, thus achieving a steady state. If moisture from the body could not evaporate right away for some reason, the fabric would absorb the moisture from the microclimate and eventually release it from the outer fabric surface to the environment, thus also achieving a steady state.

Though there are skin receptors to detect thermal sensations, there are no known humidity/moisture skin receptors. Yet, wetness in fabric can be detected by individuals (Yamakawa & Isaji, 1987; Holmer, 1985; Morooka & Niwa, 1979; Vokac et al., 1976; DeMartino et al., 1984)). Vokac et al., 1976) suggests that since there are no specific humidity receptors, these wetness/moisture sensations must be derived from the thermal and tactile receptors in the skin.

Subjects in the Yamakawa and Isaji (1987) study touched cotton broadcloth fabric samples that had moisture contents of dry (1-6%), moist (7-100%), or wet (80-640%) and temperatures of warm, medium, or cold. Subjects were asked to classify clamminess into five rankings (Fig. 10). Results showed that reports of clamminess were dependent on moisture content, the temperature of the fabric sample, and the texture of the fabric sample. When the moisture content of the sample was high and the temperature low, heat was drawn (conducted) from the skin to the sample causing an

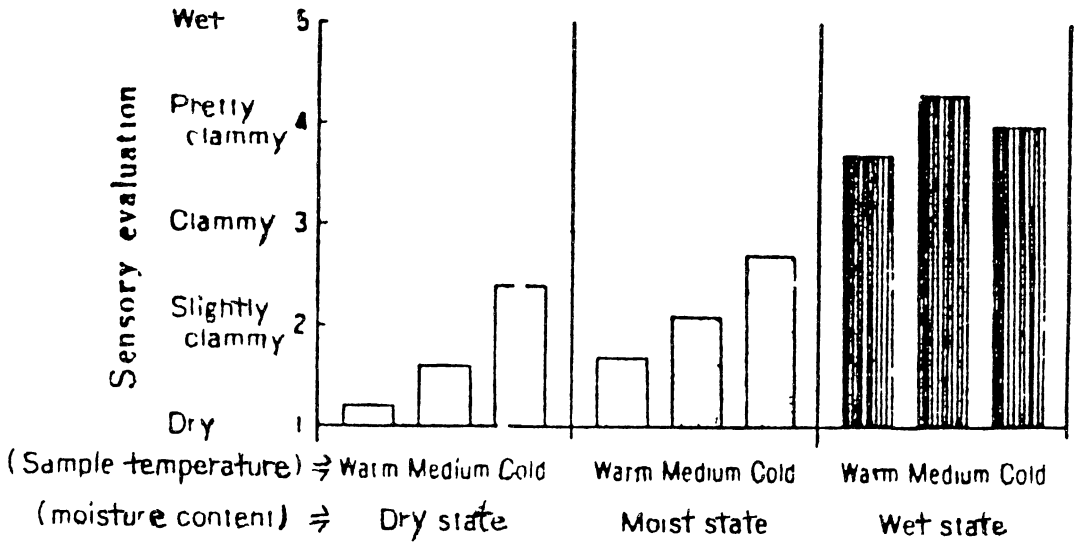

Figure 10. Result of Sensory Inspection (Cotton Broadcloth). From "Factors Affecting the Clamminess" by M. Yamakawa and S. Isaji, 1987, Journal of the Textile Machinery Society of Japan, 33(1), p. 10. Copyright 1987 by The Textile Machinery Society of Japan. Reprinted with permission.

increase in the latent heat of vaporization. Since water is a better conductor of heat than air, very moist fabric samples conducted heat better than dry samples (Yamakawa & Isaji, 1987). It was also noted in this experiment that a judgment of clamminess may be influenced by vision.

A major cause of discomfort in warm environments is moisture/sweat on the skin's surface. Skin wettedness is defined as "the fraction of skin covered with sweat necessary to account for the observed evaporative heat transfer" (Berglund, Oohori, Cunningham, & Gagge, 1985, p. 3). Humidity within the microclimate can be measured with miniature dew-point sensors placed on the skin surface (Berglund, Cunningham, & Stolwijk, 1983; Berglund et al., 1985; Graichen, Rascati, & Gonzalez, 1982).

Skin wettedness is dependent on the rate of sweat secretion and evaporation, which in turn is dependent on the vapor pressure gradient between the skin and environment (already mentioned) and the vapor resistance of the clothing and microclimate. "People seldom judge themselves to be comfortable when their skin wettedness is above about 25% of their whole body surface, but such a level may be still acceptable (Berglund et al., 1985, p. 3).

When skin wettedness levels were compared for a range of warm weather clothing at various body locations in a hot environment with no exercise, they were found to be higher on the trunk than the extremities, possibly suggestive of the trunk's increased sweat gland activity and density

(Berglund et al., 1985). However, a study conducted by Vokac, Kopke, and Keul (1972) found that the amount of moisture in the peripheral body parts of a ski ensemble worn in a cold environment with exercise, was higher than for the central body area. The authors suggested that more attention be paid to the limbs when measuring sweat and thermal comfort. This moisture was measured by weighing each item of clothing before and after the experiment to find the amount of trapped sweat.

Moisture Transport

"Comfort acceptance of garments next to the skin is in some way related to the ability of these garments to remove sweat from the skin-garment interface" (Hollies, 1977, p. 119). The ability of fabric to transport moisture is very important and has been studied in depth in research laboratories. There are several physical properties relating to moisture transport such as wettability, wicking, moisture regain, moisture content, vapor permeability, and drying rate that can be classified into two major groups, liquid and moisture vapor transport (Latta, 1977; Slater, 1977).

Liquid Moisture Transport

Liquid moisture transport refers to water transport through fabric or along the plane of the fabric. Wettability is the behavior or rate of sorption of liquid moisture when

applied to a fabric surface (Latta, 1977). The wetting process is very complex because it deals with the interaction of such things as interfacial tension, the condition of the fiber surface, and capillary action (Mehta & Narrasimham, 1987; Clark & Miller, 1978).

Improving the wettability properties of fabric may be done through caustic treatments that may pit the fabric surface. Absorbency was higher for a hygroscopically treated polyester garment than for an untreated polyester ensemble in a study by Tokura and Midorikawa-Tsuratani (1985).

A form of mass water movement which occurs through the capillaries formed by the individual fibers of the fabric is known as wicking. The rate of liquid moisture travel by wicking depends somewhat on fiber arrangement which controls capillary size and continuity (Hollies, Kaessinger, Watson, & Bogaty, 1957). It is believed that there exists a critical moisture value before the capillary action of wicking can occur (Adler & Walsch, 1984). The capillaries must be completely full so that the moisture can diffuse in and out of fibers. At moisture contents below this critical value there is not enough external pressure to move the liquid and only vapor transport occurs.

When cotton and polyester were studied for their wicking abilities, they were shown to have the same tendency to increase transport for low initial moisture contents and decrease transport for contents that were greater than their

absorptive capacities (Adler & Walsch, 1984). A finish did increase wicking in polyester shirts, but did not affect transient moisture transport between layers and did not improve comfort ratings. The extent or rate to which applied moisture wicks was found to be a function of the hydrophilic treatment to the polyester fabric. However, in knitted fabrics, wicking between layers did not transpire well as others have found, probably due to the large air spaces that increase capillary volume and decrease interfabric contact (Adler & Walsch, 1984; Latta, 1984; Hong, 1985; Farnworth & Dolhan, 1985).

Farnworth and Dolhan (1985) tested cotton (known for poor wicking) and polypropylene (promoted for very good wicking) on a sweating hot plate in combinations with a cotton/nylon blend shirt fabric. At high sweat rates, drying (the rate of evaporation from wet fabric) occurred differently for the two fabrics which was attributed to their different wicking abilities. The polypropylene indicated that wicking had transpired within the fabric, but it was not certain whether water was being transferred to the other fabric layer of shirting. Further experimentation showed that heat loss, during heavy sweating, between the two fabrics was about the same.

Liquid moisture transport between fabric layers can only occur when moisture content is very high or if a wet and dry fabric layer are held together under very high pressure (Adler & Walsch, 1984). But in actual wear,

wicking rarely occurs because garments usually don't get completely wet, except in the case of extreme exercise and very active sweating (Hong, Hollies, & Spivak, 1988). More commonly, certain regions such as the arm pit may hold higher moisture concentrations while the rest of the garment remains fairly dry (Latta, 1984). Laboratory wicking tests only measure the rate of vertical wetting which is not an indication of a fabric's ability to transport moisture, especially in actual wear (Wallenberger, Franz, Dullaghan, & Schrof, 1980).

Moisture Vapor Permeability

Moisture vapor permeability is the second grouping into which some physical properties relating to moisture transport can be placed and it can be defined as the rate or passage of water vapor through fabric (Latta, 1977). Vapor permeability is the major way moisture is transported through a fabric layer or clothing system (Hollies, 1971). Whether the moisture occurs on the skin as sweat and passes outward as a vapor, or occurs in the environment as rain and passes inward to the microclimate depends on the direction of the concentration gradient discussed before (Vokac et al., 1972).

There are three ways for moisture vapor to travel through fabric: through fiber interiors, along their surfaces, and in air spaces between the yarns (Wehner, Miller, & Rebenfeld, 1988). The dominant method of travel

is through the air spaces of the fabric which can be varied by fiber structure, because a water molecule is much more likely to diffuse through air than fabric (Mehta & Narrasimham, 1987; Wehner et al. 1988). Woodcock (1962) developed an apparatus to find the moisture permeability index for fabric and fabric systems. Results from his test show the permeability index falls with decreasing wind and rises with increasing wind, as would be expected. Experiments looking at moisture vapor permeability have shown cotton, rayon, and a 50/50 cotton/polyester blend to be most favored over modified polyester and polypropylene (DeMartino et al., 1984; Hollies et al., 1984).

Dynamic moisture changes

Because the humidity of the environment is ever-changing, it is believed that moisture levels of fabric are dynamic also. A clothing hygrometer was developed by Hollies and Penoyer (1970) to measure the moisture content of fabric surfaces next to the skin. Results of this testing device have indicated that the relative humidity around the wearer influenced the amount of moisture that condensed on the fabric surface.

A dynamic experience termed "after exercise chill" may occur when moisture accumulates in the form of condensation inside clothing as a result of unevaporated sweat (Fig. 11). This moisture will eventually evaporate after active sweating stops, cooling the body when it no longer needs to

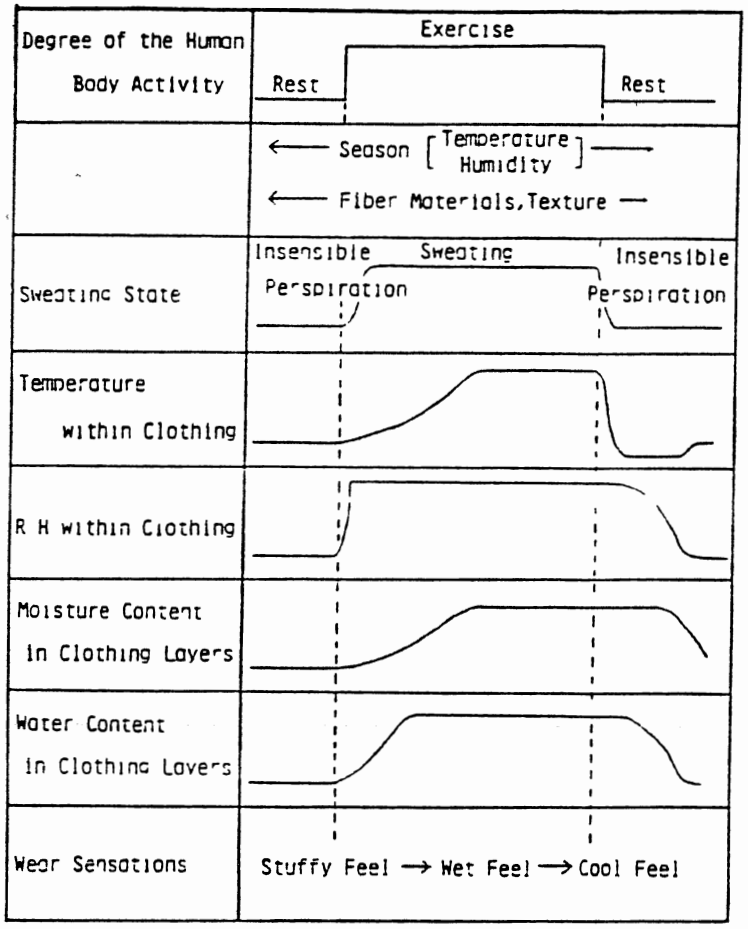

Figure 11. Model Diagram Showing Relationship Between the Degree of the Human Body Activity, the Microclimate within Clothing, and Wear Sensations. From "Fabric Properties Influencing Moisture and Heat Transport Through Fabrics" (p. 423) by K. Tsuchida, T. Harada, and S. Uchiyama, 1982. In S. Kawabata, R. Postle, & M. Niwa (Eds.), Objective Specification of Fabric Quality, Mechanical Properties and Performance, Osaka, Japan: The Textile Machinery Society of Japan. Copyright 1982 by The Textile Machinery Society of Japan. Reprinted with permission.

be, thus causing the chill (Farnworth & Dolhan, 1985; Tsuchida, Harada, & Uchiyama, 1982).

Condensation (the change from moisture vapor to liquid) can also occur when local vapor pressure rises to the saturation level at the local temperature due to the diffusional resistance of one layer of fabric or to the larger vapor pressure gradient close to the skin causing inward traveling diffusion (Farnworth, 1986).

Hygroscopic absorption of water vapor is similar to condensation because it can become trapped in clothing also, liberating its heat of vaporization and raising the temperature in the microclimate. However, absorption can occur at all vapor pressures, not just at the saturation level like condensation, and the quantity of water absorbed is limited (Farnworth, 1986).

Scheurell et al. (1985) designed the first study to observe dynamic moisture changes by applying cobaltous chloride to undyed fabric to detect moisture levels. A device to study this movement of moisture at the fabric surface was developed with a wetted chamois heated by a sweating hot plate to a skin temperature of 34° C to simulate sweating skin. Knitted cotton and polyester (with and without finishes) were held in a hoop away from the chamois to duplicate the dynamic water distillation process that can occur in clothing wear. This part of the experiment was done to see if fabrics of similar surface hairiness would pick up the same amount of moisture

independent of fiber type. While the fabrics did gain the same amounts of moisture, subjects did not perceive them similarly in terms of comfort.

In the second part of the experiment by Scheurell et al. (1985), woven cotton, polyester, and a 50/50 cotton/polyester blend were padded with cobaltous chloride, dried in hoops, and exposed to the chamois device. The purpose of using cobaltous chloride is that it forms hydrates with water that take on a range of colors from blue to pink, depending on the quantity of moisture at the fabric surface at a given time. Subjects rated these treated samples on a color index of one to ten, matching Munsell hues, which were plotted as a function of time on the device. Results indicated effects by fiber only.

It is believed that mobile water films can form on cotton's internal surface, but not on polyester's, providing mobility for condensed water at low moisture levels. These films occur in fibers that have a certain range of internal micropore sizes that when present cause water to move freely from one fabric surface to another (Scheurell et al., 1985). This travelling action can decrease the concentration of moisture next to the skin.

Other researchers have used the wetted chamois and sweating hot plate to study the fabric surfaces of cotton, polyester, and a 50/50 cotton/polyester blend fabrics (Hong et al., 1988). Results indicated that polyester has a steeper time curve and higher overall moisture vapor

pressure than cotton, with the blend falling in the middle, for both inner and outer surfaces (Figs. 12 and 13). Cotton's slow and gradual moisture buildup over time may cause people to feel dryer because vapor pressure is low and the body is not shocked physiologically by a rapid moisture increase leading to discomfort sensations (Hong et al., 1988).

The transient period in a fabric after exposure to a humidity gradient is a result of moisture sorption and flux, both of which are measurable by a device developed by Wehner et al. (1988). The amount of moisture sorption can be calculated from the original moisture content of a sample and the moisture regain value. Results of Wehner's et al. (1988) tests, while not generalizable to fiber type, showed there was competition between moisture absorption of fabric and the moisture flux across it. Absorption of these fabrics tested increased very fast then leveled out linearly. The slope of this function is known as the rate of moisture flux. As the rate of moisture sorption reaches zero the rate of moisture flux approaches a steady value (Wehner et al., 1988).

Farnworth (1986) created a numerical model to measure the combined diffusion of heat and water vapor through multiple clothing layers taking diffusional characteristics of condensation, evaporation, and sorption into account. Calculations performed in a time-dependent mode were compared to experiments with a sweating hot plate. The

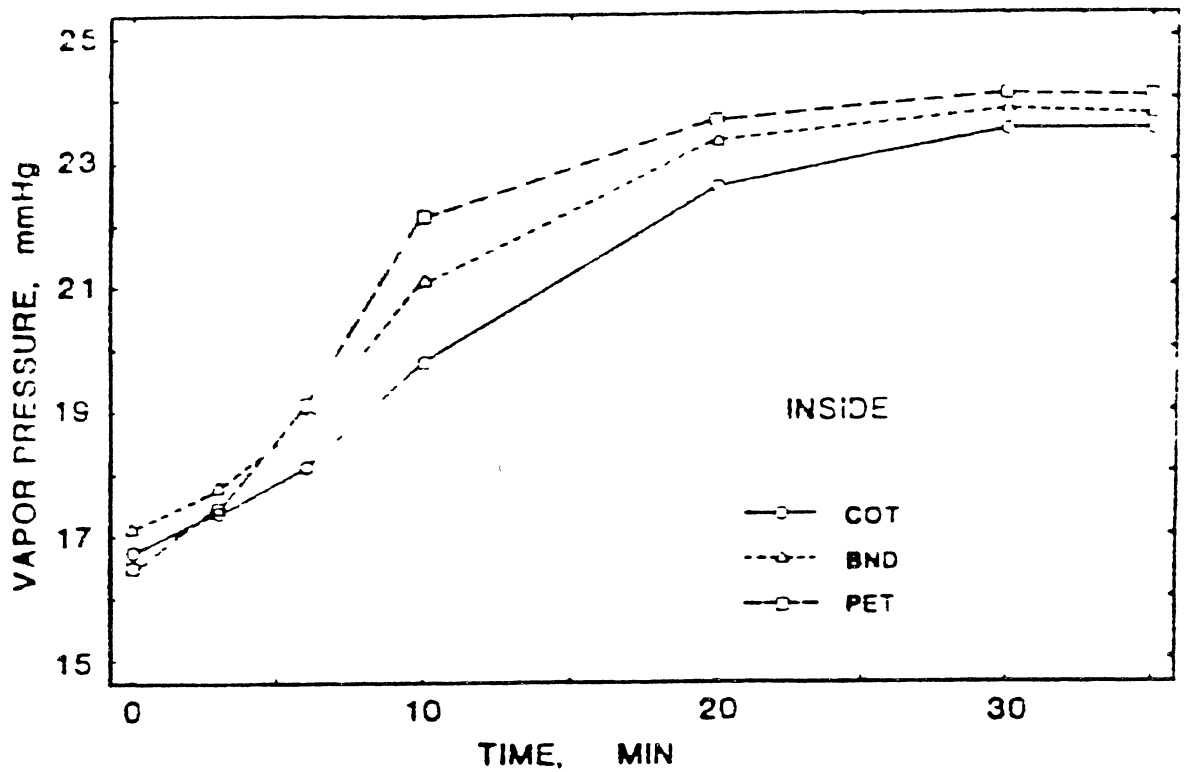

Figure 12. Dynamic Moisture Vapor Transfer at the Inner Fabric Surface. From "Dynamic Moisture Vapor Transfer Through Textiles" by K. Hong, N. R. S. Hollies, and S. M. Spivak, 1988, Textile Research Journal, 58, p. 702. Copyright 1988 by the Textile Research Institute. Reprinted with permission.

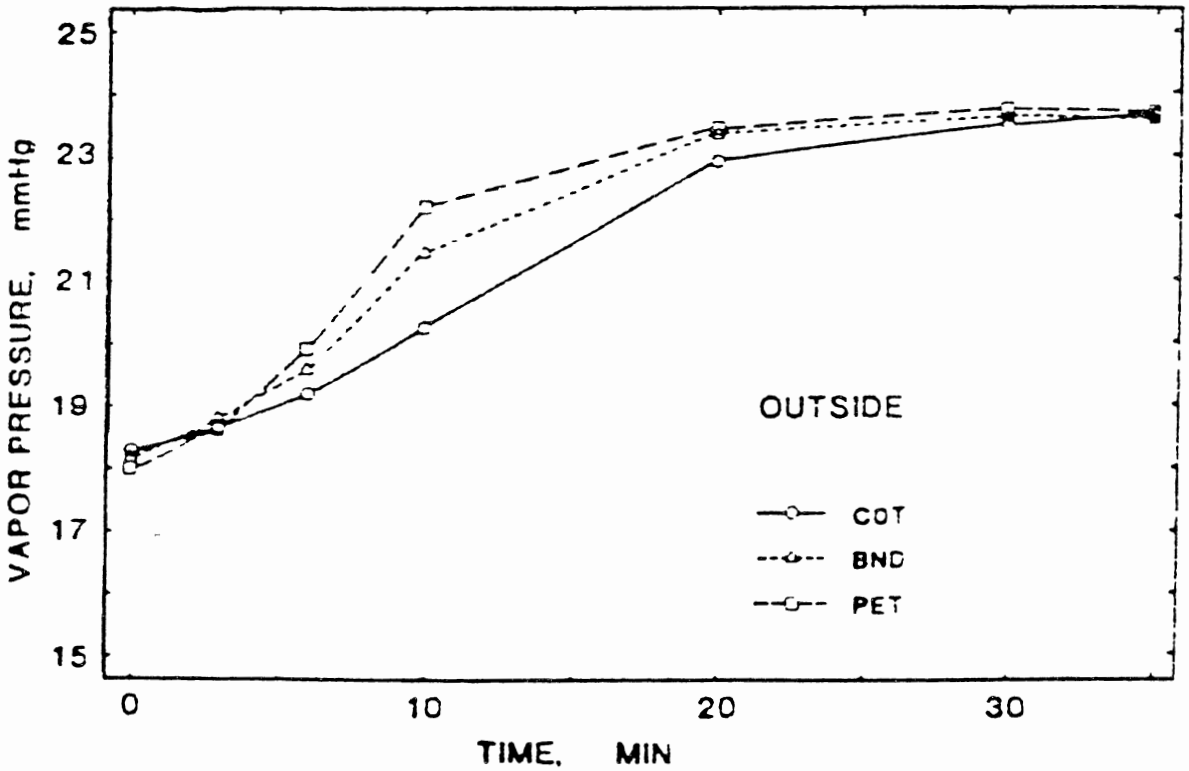

Figure 13. Dynamic Moisture Vapor Transfer at the Outer Fabric Surface. From "Dynamic Moisture Vapor Transfer Through Textiles" by K. Hong, N. R. S. Hollies, and S. M. Spivak, 1988, Textile Research Journal, 58, p. 702. Copyright 1988 by the Textile Research Institute. Reprinted with permission.

numerical model was found to be somewhat useful in understanding the interactions between condensation, evaporation, and sorption. A layer of fabric can be represented by a few numbers and its desirability can be determined from its influence on overall heat and moisture transport.

A cross section of the skin-microclimate-fabric-environment system (the triad) has been created very recently by Hong (1985) and Hong et al. (1988) (Fig. 14). The model assumes that Cs, the moisture concentration of the ambient air, is fully saturated and that the fabric surfaces (Ci and Co) include surface fibers, the entrapped air between those fibers, and the still air layer just above the fibers.

Vapor diffusion through clothing goes through phase changes (vapor and liquid) at the fabric surface. The small moisture flux along the fibers (qf) is mainly the complex process of distillation and is believed to be extremely important to clothing comfort (Hong et al., 1988). The moisture distillation process entails condensation of water vapor from the microclimate (Cm) onto the inner fabric surface (Ci), transferring a liquid film along qf to the outer fabric surface (Co) where re-evaporation and diffusion into the environment can take place (assuming it's dry).

The problem with moisture in fabric is that it is dynamic, and steady-state type test methods measure moisture after time (te) has passed, thereby excluding the dynamic

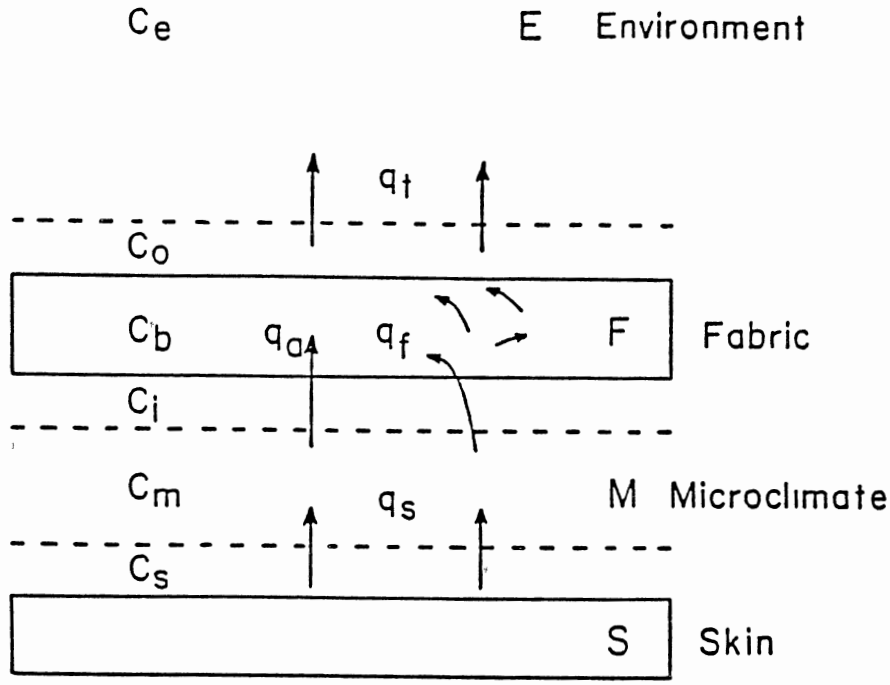

Figure 14. Cross Section of the Skin-Microclimate-Fabric-Environment System. From "Dynamic Moisture Vapor Transfer Through Textiles" by K. Hong, N. R. S. Hollies, and S. M. Spivak, 1988. Textile Research Journal, 58, p. 698. Copyright by the Textile Research Institute. Reprinted with permission.

Cs = moisture concentration at the skin surface, g/cm^3
Cm = moisture concentration in the microclimate between the skin and inner fabric surface, g/cm^3
Ci = moisture concentration at the inner fabric surface, g/cm^3
Cb = moisture concentration in the bulk fabric, g/cm^3
Co = moisture concentration at the outer fabric surface, g/cm^3
Ce = moisture concentration in the environment, g/cm^3
qs = moisture flux from the skin, $g/cm^2/sec$
qa = moisture flux through the open air space in the fabric, $g/cm^2/sec$
qf = moisture flux passing along internal pore surfaces in fibers, $g/cm^2/sec$
qt = moisture flux passing through the fabric, $g/cm^2/sec$

region AOB (Fig. 15). Wear tests usually occur over time, taking the transient area into consideration. Dynamic surface wetness methods deal with moisture transfer prior to the time it takes to reach equilibrium, between points B and A. Hong (1985) and Hong et al. (1988) studied the contribution of fabric surfaces (Ci and Co) in relation to the area OAB to determine whether it varies by fiber or finish and how it effects moisture concentrations in the microclimate at Ci, Co, Cb, and Cm. Results reported earlier, indicated that there were differences by fiber type (see Figs. 12 and 13), and the effect of finishes on the area OAB will be the topic of an upcoming paper by the authors.

Psychophysics

Psychophysics is the scientific study of the relationship between stimulus and sensation (Gescheider, 1976). Stated another way, it is how the magnitude or intensity of a psychological sensation or experience is related to a variable physical stimulus (D'Amato, 1970).

A German physicist, Gustov Fechner, was the first to develop a method of measuring the relationship between body and mind, or between physical stimuli and the resulting conscious sensation (Engen, 1971). The physical realm or continua may contain such factors as environmental conditions, body temperature, and clothing characteristics like fabric thickness and weave, fiber or yarn composition,

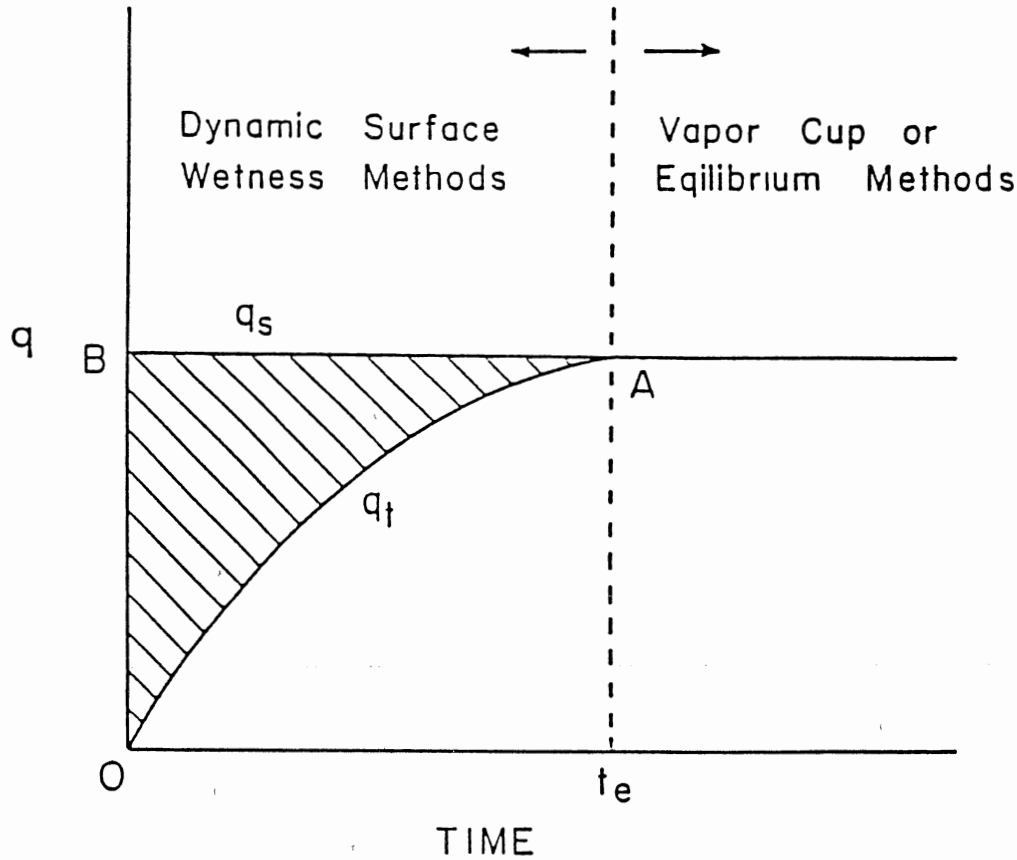

Figure 15. Generalized Determination of Moisture Transfer Variables. From "Dynamic Moisture Vapor Transfer Through Textiles" by K. Hong, N. R. S. Hollies, and S. M. Spivak, 1988. Textile Research Journal, 58, p. 699. Copyright by the Textile Research Institute. Reprinted with permission.

Area OAB = area between qs and qt equals the amount of moisture held near skin, microclimate, inner fabric surface, bulk fabric and outer fabric surface.

te = time to reach equilibrium for moisture build up in the microclimate M.

finish, or design, all of which can be determined easily (Sweeney, 1988). The psychological realm is harder to assess and may include perceptions of loudness, brightness, roughness, comfort, or even wetness.

Gustov Fechner, in the early 1800's, developed what are now called the classical psychophysical methods to show the relationship of mind to matter and suggested that "an increase in the physical intensity of a stimulus corresponded to an increase in mental intensity" (Snodgrass, 1975, p. 19). He proceeded to develop methods of empirically measuring psychological responses to physical stimuli and treated the results mathematically.

"The complete sequence of events in any psychophysical determination is:

Stimulus ---> Sensation ---> Judgmental Response" (D'Amato, 1970, p. 120). Traditional psychophysics concerns itself with the relationship between the stimulus and the resulting sensation because the goal is to create experimental conditions which will ensure agreement between the sensation and judgmental response. Specifically, Fechner's methods of classical threshold theory deal with detection and discrimination of stimuli which can be measured by the absolute and difference thresholds. Other researchers have focused on the correspondence of the sensation experienced and the judgmental response, labeling it signal detection theory. This theory takes into account subjects' expectations and the advantages and disadvantages

of wrong decisions (D'Amato, 1970).

Absolute Threshold

The absolute threshold (abbreviated AL) or limen (its Latin denotation) is the smallest amount of stimulus energy necessary for an observer to detect a stimulus (Goldstein, 1980). A common definition of the AL is "the stimulus value that evokes a sensation 50% of the time" (D'Amato, 1970, p. 119). This statistical value may vary from one psychophysical method to another because it is not a fixed quantity but rather one that varies over time and is ever-changing.

Difference Threshold

The difference threshold (abbreviated DL) is the smallest amount of stimulus energy required to yield a perceived sensation difference, termed the just noticeable difference (JND) between a variable and standard stimulus (D'Amato, 1970; Gesheider, 1976). These comparison stimuli are used to assess human discrimination between different stimulus intensities or amounts. "If the intensity of the stimulus is 10 units and the stimulus has to increase to 12 units to produce a JND, the DL would be 2" (Gescheider, 1976, p. 2). The JND is not a constant value, but one that rises linearly with the size of the standard stimulus (Coren, Porac, & Ward, 1978). In other words, as the stimulus intensity increases so does the size of the change needed for discrimination to occur.

Weber's Law

For many sense modalities the relationship between the size of the DL and the intensity level of the stimulus is known as Weber's law and is written:

$$\Delta \phi / \phi = c$$

The change in the stimulus intensity that can just be discriminated ($\Delta\phi$) is a constant fraction (c) of the starting intensity of the stimulus (ϕ) (Gescheider, 1976). More simply, it is the proportion by which the standard must be increased in order to detect a change. The larger the Weber fraction is the larger the JND's will be (Coren, Porac, & Ward, 1978). Weber's law is very useful for sensory discrimination comparison, but it does not apply well to extremes of the stimulus range. The fraction appears to increase disproportionately, in particular for low intensities in the stimulus range (Engen, 1971; Gesheider, 1976).

Psychophysical Methods

There are three popular psychophysical methods that were developed by Fechner to explore the laws relating sensory experience to traits of the initiating stimulus: the method of limits, the method of constant stimuli, and the method of adjustment. D'Amato (1970) states that an important feature of all three methods is that they call upon the subject to make the simplest possible judgments:

> to detect the presence or absence of a sensation or to decide whether two sensations are equal in magnitude or different. These discriminations are among the most reliable judgments of which organisms are capable (p. 118).

The method of constant stimuli is regarded by Guilford (1936) as the most accurate and widely used psychophysical method and it has also been shown by Sweeney (1988) to be workable in assessing moisture sensation in fabric. For these reasons only the method of constant stimuli will be reviewed.

Method of Constant Stimuli

The method of constant stimuli requires that a constant or fixed set of stimuli be presented in random order repeatedly to each observer (Coren et al., 1978). The number of different stimulus values may vary from four to eight or five to nine stimuli (D'Amato, 1970; Gescheider, 1976).

Superthreshold and subthreshold values should not be included, rather the stimulus values should range from those that will almost never be perceived or perceived on a little more than 0% of the trials to those that will almost always be perceived or perceived on a little less than 100% of the trials (D'Amato, 1970). The estimated AL value should be located within this stimulus range, sometimes termed the transition zone, 50% of the time (Engen, 1971).

The method of constant stimuli requires a large number of trials or presentation of stimuli. Ten, twenty, or even

one hundred presentations of each stimulus intensity are recommended (D'Amato, 1970; Snodgrass, 1975; and Guilford, 1936). It is also suggested that some preliminary observations, testing, and planning be done to locate the estimated AL and super- and subthresholds (Engen, 1971).

Absolute Threshold. To determine the AL with the method of constant stimuli, the subject when presented with a stimulus responds "yes" if they detect it and "no" if they do not. Each stimulus must be presented an equal number of times and the yes or no responses are recorded together with the intensity of each stimuli. These responses are converted to z scores and plotted on the vertical or Y axis against the stimulus intensity on the horizontal or X axis. The method of least squares is used to determine the line of best fit to the data points and the AL is located approximately in the center of this line. If these points create the psychometric function as an s-shaped ogive, a cumulative form of a normal distribution, a linear function will result (Gesheider, 1976). Sweeney's (1988) research showed that moisture sensation emulates other sense modalities in this way.

Difference Threshold. To determine the difference threshold with the method of constant stimuli, the subject is randomly presented a standard stimulus and a comparison or variable stimulus and must discriminate if one is "greater than" or "less than" the other. Using the two categories of

"greater" and "less than" is known as the forced choice procedure (D'Amato, 1970). A variation of this method that is more difficult allows a third judgment of "equal to" to be included.

Normally five, seven, or nine values of variable stimuli are used with equal increments of separation and equal numbers above and below the standard stimulus value. Gescheider (1976) states that "the values of the comparison stimuli are chosen so that the stimulus of the greatest magnitude is almost always judged greater than the standard and the stimulus of least magnitude is almost always judged less than the standard" (p. 24).

The two stimuli are paired together for a sufficient number of trials to get an estimate of the proportion of greater responses which are converted to z scores and placed on the vertical or Y axis. These responses are plotted against values of the variable stimulus on the horizontal or X axis to create the psychometric function. Again this psychometric function has been shown to be an s-shaped ogive for many sense modalities, including moisture sensation (Sweeney, 1988).

When a subject must make a forced choice between two categories and respond greater or less when no difference between the standard and comparison stimuli can be perceived, we expect the judgmental responses to be split half and half (above and below 50%) an equal proportion of times (Snodgrass, 1975). "This .5 point (out of 1.0) is

known as the point of subjective equality (PSE) on the psychometric function, and represents the value of the comparison stimuli which over a large number of trials is perceived to be subjectively equal to the standard stimuli (Gescheider, 1976, p. 26). The method of least squares is used to find the line that best fits the data from which the PSE is determined.

The PSE of the DL is somewhat similar to the 50% value in the AL (Engen, 1971). Usually the PSE is not exactly the same as the actual standard stimulus value and this difference is known as the constant error (CE). Constant error is caused by uncontrollable factors that often influence psychophysical results when successive presentations of stimuli are made to two separate body locations (Gescheider, 1976).

On the psychometric function an upper and lower difference threshold may be found. The upper threshold (UT) is the value of the comparison stimuli judged higher than the standard 75% of the time or explained another way is the range from the PSE to the .75 point. The lower threshold (LT) is the value of the comparison stimuli judged lower than the standard 25% of the time or is the range from the PSE to the .25 point. These points are chosen because 75% and 25% are in between zero discrimination at the 50% point and perfect discrimination at the 0% and 100% points (D'Amato, 1970).

The difference between the UT and LT is termed the

interval of uncertainty (IU) because it is in this range that the subjects cannot discriminate between the standard and variable stimuli (D'Amato, 1970). This IU is simply the semi-interquartile range of the normal distribution whose ogive is represented by a linear function. The UT and LT can be averaged to find the DL.

Error. The standard and comparison stimuli may be presented to different areas of the body simultaneously or to the same area at different times, depending on the experiment. Space error can occur when stimuli are presented to different body areas and judgmental responses are affected. To eliminate this type of error the standard stimulus can be presented to each receptor area half of the time (Gescheider, 1976).

Time error can occur when stimuli are presented to the same body area at different times because the subject must compare the variable stimulus with a memory of the standard. The order of presentation of the comparison stimuli is the cause of time error. When the same stimuli is always presented first the second stimulus is judged greater than it. To cancel this effect, the standard stimulus can be presented first on half of the trials and second on the other half accordingly with the variable stimuli (Gescheider, 1976).

CHAPTER III

METHODOLOGY

Test Facility

Testing was done in an environmentally controlled chamber at Oklahoma State University located in the Veterinary Medicine College. Environmental conditions for testing were considered thermally comfortable at 26° C ± 2° and 50% relative humidity ± 2%, with air movement of less than .15 meters/second. These parameters have been determined by the American Society of Heating, Refrigerating and Air Conditioning Engineers which sets environmental conditions for thermal comfort in built, artificial environments for lightly clothed subjects (ASHRAE Standard 55-1981).

Subjects

Female volunteers, ages 19 to 23, were recruited and pre-screened for moisture sensitivity before being accepted as test subjects. Previous research by Sweeney (1988) indicated that preliminary moisture sensitivity testing was necessary because individuals display differences in their ability to perceive moisture. The skin with varying numbers

of sweat glands, receptors, hairs, and ridges all over the body is not a uniform sensory surface (Schmidt, 1978). Subjects completing the pre-screening were paid five dollars for their cooperation. An additional twenty-five dollars was paid to those 15 subjects who participated in the entire study.

Test Fabrics

A total of four different test fabrics was used in this study, all of which were suitable to be worn next to the skin as lightweight T-shirts. Fabric A was a 50/50 cotton polyester blend in a plain knit fabric construction. It was the same fabric that was used in previous moisture sensation research by Sweeney (1988). Fabric B was a 100% cotton in a plain knit fabric construction.

Fabric C was a 100% polyester with a special four channel fiber shape in a plain knit fabric construction. This unique fiber structure was engineered to allow for a larger surface area to promote greater wicking and evaporation of moisture.

Fabric D was a double-sided fabric with a specialty nylon fiber on one side and cotton on the opposite side. This fabric was engineered for the specialty nylon side to be worn next to the skin, facilitating wicking to the outer cotton layer so that evaporation may occur.

Pre-Testing

Mapping

All moisture sensitivity mapping was done on the dorsal region (back side) of both hands in a thermally comfortable environment, controlled by an environmental chamber. This body location was chosen because the fabric in a glove would likely be in contact with the back of the hand at all times as opposed to the palm due to the action of grasping and releasing which could cause fabric to bunch up and/or pull away from the palm. The backs of the hands of each subject were visually scrutinized to determine where a glove would likely make contact with the skin. The identified location for mapping depended on the structure of bone, muscle, and cartilage in the dorsum region of the hands. A template with 20 punched holes spaced 1/2 inch apart was placed on each hand with the top corner hole just below the knuckle of the index finger. A pen mark was made on the skin through each of the 20 holes. These marks provided a map for proper fabric placement for each of the 1/2 X 1/2 inch fabric stimuli. Subjects' responses as to whether they detected the presence of moisture or not were recorded.

Fabric Stimuli

Twenty 1/2 X 1/2 inch swatches of fabric A served as the physical stimuli for the pre-testing. The swatches were wetted with .10 ml of water since previous research

(Sweeney, 1988) indicated that this amount was easily detectable by most subjects.

Protocol

With all jewelry on the hand and wrist removed and the arm extended with the palm facing down on a flat table covered with cardboard and white medical examining table paper, subjects were presented with the fabric stimuli for five seconds. They were asked to respond "yes" if they detected moisture and "no" if they did not. Each of the twenty 1/2 X 1/2 inch fabric swatches were presented randomly so that moisture sensation in each hand could be assessed. A paper towel was used to blot excess moisture from subjects' hands. Those subjects who sensed moisture on at least 70% of the presentations to each hand were termed moisture sensitive and were allowed to participate in the rest of the study. Fifteen subjects were pre-screened for moisture sensitivity and all passed. A large box with a three inch horizontal slit cut out of the bottom front (for subjects' hands) was covered with white paper and acted as a barrier to prevent subjects from seeing the fabric stimuli, their hands, or the investigator.

Testing

Fabric Stimuli

Swatches of fabrics A, B, C, and D measuring 2 X 2 inches were used as the physical stimuli and were contained in small glass moisture-proof bottles. Moisture was removed from the swatches using ASTM Method D 2654, procedure one (1986). The fabric swatches were placed wrong side up in the bottles and distilled water at room temperature was applied with a Hamilton Microliter syringe. The syringe was kept at a constant angle and height from the swatch surfaces. Immediately after the water application the bottle was capped to prevent moisture loss to the environment.

Threshold Determinations

Determination of Absolute Threshold. The physical stimulus range determined from Sweeney's study (1988) was extended so that a more accurate absolute threshold (AL) of moisture sensation could be determined. In that study the moisture amounts ranged as follows: .00, .01, .02, .03, .04, and .05 ml, with the AL empirically determined to be .024 ml. The range of response probabilities to stimulus values was empirically determined to be 28% to 77%, not quite the full range the researcher would have liked to most accurately determine AL for moisture sensation. The response probabilities should ideally extend from a little

more than zero percent to a little less than 100%. Following this reasoning, fabric swatches in the present study contained eight different moisture amounts as follows: .00, .005, .015, .025, .035, .045, .055, and .065 ml. It was anticipated that these stimulus values would extend from being perceived a little more than zero percent of the time, or almost never, to being perceived a little less than 100 percent of the time, or almost always, to more fully capture the desired range necessary to most accurately determine the AL of moisture sensation in the selected fabrics (D'Amato, 1970).

Determination of Difference Threshold. The physical stimulus range for determining the difference threshold (DL) was also expanded from Sweeney's (1988) study, where moisture amounts were: .03, .05, .07, .09, .11, .13, and .15 ml. The DL was empirically determined to be .0385 ml. and the range of response probabilities to the stimulus values was 18% to 85%. Again the empirically determined range was not as extensive as the psychophysical literature recommends to most accurately determine DL. Following this reasoning, fabric swatches in the present study contained the following amounts of moisture: .015, .040, .065, .090, .115, .140, and .165 ml. The .09 ml stimulus value was the standard stimulus to which the variable stimuli were compared. It was anticipated that the variable stimuli values chosen with the most moisture would be judged greater

than the standard stimulus most of the time, and the variable stimuli with the least moisture would be judged less than the standard stimulus most of the time (Gescheider, 1976).

Protocol

Upon entering the test chamber subjects were asked to remove any rings, watches, or bracelets they had on. Before actual testing began, subjects were allowed to experience the sensations of a completely dry fabric swatch and one wetted with .165 ml of water, which was the highest amount used in this study, for all four fabrics. They were reminded to make their judgmental response based solely on the sensation of moisture, not temperature (cold/hot) or pressure. Subjects were required to extend both of their arms out onto a flat table surface covered with cardboard and white medical examining table paper, with the palm side down. Each 2 X 2 inch fabric swatch was removed from its bottle with forceps and presented to the subjects' hands. The subjects' view of the stimuli, their hands, and the investigator was obstructed by a large box covered with white paper.

Absolute Threshold. Subjects were randomly presented with a fabric stimuli for five seconds, after which they were asked to respond "yes" or "no" as to whether they felt the presence of moisture or not. Four presentations of each

of the eight stimulus intensities were performed, constituting 32 total trials for each of the four fabrics.

Difference Threshold. The standard and variable stimuli were presented to subjects' opposing hands at different times for a period of five seconds. To eliminate space error, the standard stimulus was presented to one hand for half of the presentations and to the other hand for the remainder of the presentations. To eliminate time error, the standard stimulus was presented to the right hand for half of the presentations and to the left hand for the other half of the trials. After each presentation of the stimulus pairs the subject was asked to respond whether the variable stimulus was "greater" or "less" than the standard stimulus. Four presentations of each of the seven stimulus intensities were performed, constituting 28 total trials for each of the four fabrics.

CHAPTER IV

MANUSCRIPT I

Influence of Fabric on Threshold Determinations for Moisture Sensation

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ABSTRACT

Moisture transport and build-up on the skin, in the microclimate, and within fabric is a critical problem particularly in functional apparel and is known to influence the perception of clothing comfort. This study determined fabric influence on moisture threshold determinations using the psychophysical method of constant stimuli. Swatches of four selected fabrics designed to be worn next-to-the-skin were wetted with specified moisture amounts and applied to the back of the hands of fifteen female volunteers. The hand represents a significant problem area when protective gloves are worn because of thermal and non-thermal sweating. The data were transformed and fitted to regression lines by fabric. These lines measured detection by moisture levels and were determined to be significantly different. For one fabric, subjects detected extremely small amounts of moisture. Subjects' abilities to discriminate between two different moisture levels by fabric were determined to be significantly different. These results can be attributed to fabric characteristics.

Clothing comfort is fascinating, yet it has no universally accepted definition. This non-agreement on definition by experts may exist because comfort is dynamic, differing by person, environment, fabric structure, or fiber type. Defined by Branson and Sweeney [3] in a position paper, it is "a state of satisfaction indicating physiological, psychological and physical balance among a person, his/her clothing, and his/her environment" [p. 14].

Clothing comfort can be critically influenced by the physical movement/transport of water through fabric [10, 14, 18]. The presence of moisture in fabric, even in very small amounts, can cause comfort ratings to decrease when fabric is interfaced with human skin [8, 9, 16].

There are two main types of moisture transport through fabric: liquid and vapor forms. Mass liquid transport occurs through fabric or along the plane of the fabric and is known as wicking. Wicking may occur only in extreme situations (heavy exercise) where total saturation occurs, but does not usually occur in actual wear [12]. The second type of transport, moisture vapor transport, is the most common method of moisture transport through fabric, usually occurring through the small air spaces [10, 14, 21].

Psychological scaling techniques are used most often to assess comfort in human subjects. However, some of these scales measuring general comfort, thermal sensations, and humidity/wetness sensations yield different results, thus possibly not measuring sensations in the same way [5, 13].

To alleviate these dissimilarities, psychophysical scaling may be used as an alternative method to measure a sensation because of its direct relationship to an initiating physical stimulus of a known intensity. In psychophysical testing a subject must detect a sensation's presence or absence and must discriminate between the sensations of a variable and standard stimulus, and decide whether the variable stimulus is greater or less than the standard in stimulus intensity. These simple tests are "among the most reliable judgments of which organisms [humans] are capable" [4, p. 118].

The purpose of this study was to use the psychophysical method of constant stimuli to investigate the influence of fabric on threshold determinations for moisture sensation. The dorsal (back) region of the hand was chosen as the test site because a glove would likely make contact with the skin in this area. Moisture in clothing is often a reason for garment discomfort or dissatisfaction, especially in functional clothing ensembles or athletic or protective gloves. Hot or stressful environmental conditions may cause moisture to accumulate on the skin, in the microclimate, or within the fabric layers of a garment or gloves, resulting in wearer discomfort, decreased dexterity, or impaired performance. The objectives of this study were 1) to determine the absolute and difference thresholds for moisture sensation for the dorsal region of subjects' hands using four selected fabrics, and 2) to explore how fabric characteristics influenced moisture sensation in this body

location.

THEORETICAL FRAMEWORK

Psychophysics can quantitatively assess the relationship between physical stimuli and psychological sensations, thus providing the theoretical foundation for this research. Sensory research is based on psychophysics because a "felt" sensation occurs in response to some physical stimulus, like wetness. While the physical realm is easily measurable in some type of unit (temperature, moisture content), the psychological realm is more difficult to assess because the sensations involved (comfort/discomfort or wetness/dryness) are so dynamic and dependent on other variables. The relationship between the two realms depends on "the complete sequence of events in any psychophysical determination is:

Stimulus -----> Sensation -----> Judgmental Response" [4, p. 120].

The sensory threshold concept is key to the study of psychophysics. The absolute threshold (abbreviated AL) is the minimum value of a physical stimulus that will evoke a sensation fifty percent of the time [4]. The difference threshold (abbreviated DL) is the smallest amount of stimulus energy required to produce a perceived sensation difference, known as the just noticeable difference (JND), between a variable and standard stimulus [4, 6]. The JND is not constant, but increases linearly with the size of the

standard stimulus. As the stimulus intensity increases so does the size of the change needed for discrimination to occur. The relationship between the size of the DL and the intensity level of the stimulus is known as Weber's law and is written:

$$\Delta\phi/\phi = c \qquad \text{(Equation 1).}$$

The change in stimulus intensity that can be just discriminated ($\Delta\phi$) is a constant fraction (c) of the starting intensity of the stimulus (ϕ) [6]. Weber's law has been shown to hold for many sense modalities over a wide range of stimulus intensities and is useful for comparing sensory discrimination.

The method of constant stimuli is the most accurate and widely used of the three psychophysical methods [7]. The stimulus intensities are selected so that they will be in the vicinity of the threshold and are presented randomly. Since Sweeney [19] showed that the method was feasible in assessing moisture sensation in fabric, it was also used in this study. The method of constant stimuli requires subjects to respond "yes" or "no" for the determination of the AL and "greater" or "less" than for the determination of the DL. Explanation of this method is given by D'Amato [4] and Gescheider [6].

Methods and Procedures

TEST FACILITIES

The study was conducted in an environmentally controlled chamber at Oklahoma State University. Environmental conditions for testing were 26° C ± 2°, 50% RH ± 2°, and air movement of less than .15 m/s. These conditions are considered thermally comfortable by ASHRAE Standard 55-1981 [1].

SUBJECTS

Fifteen paid female volunteers, ages 19-23, were recruited and pre-screened for moisture sensitivity before being accepted as test subjects. Preliminary moisture sensitivity testing was necessary because not all individuals are sensitive to moisture due to individual differences in the skin as a sensory surface [17, 19].

PRE-SCREENING

Moisture sensitivity mapping was done on the dorsal region of both hands because individuals display differences in their ability to perceive moisture [18]. A 5 X 7.4 cm template with 20 holes, spaced 1.3 cm apart, was placed on each hand with the top corner hole just below the knuckle of the index finger. A pen mark was made on the skin through each of the 20 holes. These marks provided a map for the proper placement of the 1.3 X 1.3 cm fabric stimuli. Only fabric A was used for the pre-screening. These small

swatches were wetted with .10 ml of water, an amount previously determined to be easily detectable [19]. Data sheets with template-size grids for each hand were used to record subjects' responses (Appendix C).

The pre-screening protocol required subjects to remove jewelry from their hands and extend their arms out onto a flat table with palms facing downward. Subjects were randomly presented the fabric stimuli for 3-5 seconds and asked to respond as to whether they detected moisture or not. Each fabric swatch was presented to a random location on the grid so that moisture sensitivity could be assessed for each hand. A towel was used to blot excess moisture from the skin surface. A barrier between the subjects and the investigator prevented any visual influence.

Subjects sensing moisture correctly at least 70 percent of the time on each hand were termed moisture sensitive and allowed to participate in the remainder of the study. All 15 subjects screened were determined to be moisture sensitive.

TESTING

All fabric was laundered and dried once before being cut. The four selected fabrics were all designed to be worn next-to-the skin. Swatches of fabrics (A, B, C, and D) measuring 5 X 5 cm served as the physical stimuli (Table 1).

Table 1 about here

Moisture was removed from the swatches according to ASTM Method D 2654 [2], procedure one. Fabric swatches were placed wrong side up in small glass moisture-proof bottles. Distilled water was applied with a Hamilton Micro-liter syringe held at a constant angle and height from the swatch surfaces.

Subjects entered the test chamber and were asked to remove any jewelry from their hands and to extend their arms forward with palms facing downward. Before actual testing began, subjects were allowed to experience a completely dry and wet (.165 ml) swatch of each of the four fabrics. They were reminded to make their judgmental responses solely on the sensation of moisture, not temperature or pressure. Again, subject's views of the stimuli, their hands, and the investigator were obstructed. The order of presentation to the right and left hands, the order of fabrics, and the order of stimulus intensity were randomized. Data sheets are shown in Appendix D.

For determination of the ALs, a fabric swatch was removed from the bottle with forceps and placed on the subjects' appropriate hand for 3-5 seconds. After the removal of each swatch subjects' hands were blotted. Subjects then responded "yes" or "no" as to whether they detected the presence of moisture or not. The stimulus

range for the AL was as follows: .000, .005, .015, .025, .035, .045, .055, and .065 ml. Four replications were performed for each of the four fabrics, constituting 128 total trials for each of the 15 subjects.

For determination of the DLs, subjects were presented a variable and a standard stimulus to opposing hands for 3-5 seconds each. Subjects' hands were blotted after the removal of the second swatch. After the paired presentation they were asked to respond to the question--"Was the variable stimulus "greater" or "less" than the standard stimulus in wetness". The stimulus range for the DL determinations was as follows: .015, .040, .065, .090, .115, .140, and .165 ml. The .090 ml stimulus value was the standard stimulus to which the variable stimuli were compared.

On half of the trials the standard stimulus was presented first and on the other half of the trials the variable stimulus was presented first. In addition, the standard stimulus was presented to the right hand on half of the trials and to the left hand for half of the trials. At all times the variable and standard stimulus pairs were of the same fabric. The order of fabrics and the order of stimulus intensity were also randomized. Data sheets are shown in Appendix D. Four replications were performed for each fabric, constituting 112 total trials for each of the 15 subjects.

Results and Discussion

ABSOLUTE THRESHOLD

To determine the AL, the percentage of "yes" responses was computed for each subject by fabric and by stimulus intensity (see Appendix F). The psychophysical literature suggests that sense modality data form an ogive (s-shaped) curve [6]. Sweeney's study [19] found this to be true for moisture sensation also. Examination of the graphs by subject suggested that fabric C did not follow an ogive curve. Instead a sharp increase occurred for most subjects between the .000 and .005 moisture levels for this fabric.

In examining subject graphs it was also noted that everyone but subject six sensed moisture 100% of the time at .015 ml. At .005 ml five subjects sensed it wet 75% of the time and eight subjects sensed it 100% of the time, but subject six sensed it only 50% of the time. Therefore, it was decided not to include data from subject six in further analyses. It should be noted that subject six was the largest subject in terms of physical body size (height and weight), indicating that size may make a difference in moisture sensation.

Subject data were combined to determine percentage of "yes" responses by fabric and by stimulus intensity. The data were then transformed, converting percentages to z scores using the probit transformation (50% equals a z score of 0). The z scores were plotted on the Y axis against the

stimulus intensity values on the X axis using the method of least squares ($Y = a + bx$) so that the psychometric function could be observed (Figure 16).

Fig. 16 about here

The psychophysical literature suggests that sense modality data when transformed will result in a linear trend [6]. Fabrics A, B, and D demonstrated significant linear relationships between subjects' responses and moisture ($p \leq .01$). This means that as the moisture level in the swatches increased, subjects detected the swatches as being wetter. The percent of explained variation between the data points and the predicted lines were 82%, 84%, and 97%, respectively. Fabric C did not exhibit a significant linear relationship because of its early detection by subjects at .005 ml of moisture. Only 37% of the variation in the data points from the line was explained. This suggests that fabric C's data points do not fit a regression line very well, thus it is questionable whether moisture content in fabric C demonstrates a psychometric function (Table 2).

Table 2 about here

Perhaps the stimulus values were not as appropriate for fabric C as they were for the other fabrics. A proper psychometric function for fabric C would likely occur

between .000 and .005 ml of moisture.

The absolute threshold (AL) values for each of the four fabrics were found by the equation:

$$z = a + bx \qquad \text{(Equation 2)}$$

where z = 0. The ALs for fabrics A, B, C, and D were determined to be .018, .025 -.012, .021 ml, respectively. In Figure 16 the point at which each fabric's regression line crosses the z = 0 line is the AL. Notice fabric C does not cross this line in the quadrant shown. While this negative AL value is hard to understand in a practical sense, negative thresholds are sometimes found in the literature when idealized outcomes with a step-like function of sharp detection (0-100%) take place [6]. Fabric C exhibited this step-like function of sharp detection between .000 and .005 ml of moisture.

Fabric C is the thinnest and lightest-weight fabric with a special four channel fiber engineered to promote wicking (from Table 1). Although wicking may not occur in actual everyday wear, it might occur in very active or stressful situations where total moisture saturation occurs. Wicking should pull moisture away from the skin to the outer fabric surface for evaporation, so if wicking did occur why was moisture sensed right away? It could be that wicking did not occur at such a low moisture level so that the moisture was held within the fabric, making it easily detectable.

Fabric C also has the smoothest inner and outer fabric

surfaces. These surface characteristics may have caused moisture to be held within this fabric differently than in the other fabrics [12] and/or to be distributed differently/uniquely throughout the fabric. The smooth surfaces of fabric C may have allowed it to contact the skin more easily, possibly making the moisture more easily detectable. In a preliminary lab experiment, .005 ml of water spread faster vertically and horizontally in fabric C than in the other fabrics. This larger wet area allows more wet fabric to touch the skin, possibly causing moisture in fabric C to be detected more easily.

Fabric B stands out as the next most different fabric because of its highest AL value and lowest DL value. From Table 1, one can see that fabric B is the thickest and heaviest fabric, it also had the roughest/hairiest inner and outer fabric surfaces. These factors might have caused the moisture in fabric B to be harder to detect, but also easier to perceive/discriminate a sensation difference when two stimuli were used. The rough surfaces of fabric B may have caused it not to make contact with the skin well except when it was very wet.

The AL value for fabric A was .018 ml in this study as compared to .024 ml in Sweeney's study [19]. The stimulus range of responses was from 1.8% to 99% for this study and 28% to 77% for Sweeney's [19]. These differences could be a result of having extended the range of moisture intensities used by Sweeney [19] or the physiological difference in body

sites between the scapular region used by Sweeney [19] and the dorsal region of the hands.

The stimulus ranges for each fabric in this study closely approached the 1% to 99% of detection required for accurate psychophysical threshold determinations (Table 2). The raw data for fabrics A, C, and D included the 0% (none detected) and 100% (all detected) detection points. Data transformation using the probit function does not recognize 0% and 100% as acceptable values. To alleviate this problem .01 was substituted for .00 and .99 was substituted for 1.00 so that the total eight points could be statistically interpreted.

The regression assumptions are met exactly when Equation 2 is fitted, but its use to estimate a moisture value (AL, DL, PSE, UT, LT) for given z values is known as inverse regression. Following Neter, Wasserman, and Kutner [1], the variance of a moisture estimator using inverse regression is given by

$$V(\hat{X}_n) = \frac{S^2}{b^2}\left[\frac{1}{n} + \frac{(\hat{X}_n - \overline{X})}{\Sigma(X_1 - \overline{X})_2}\right] \qquad \text{(Equation 3)}$$

when the $\hat{X}_n$ is interpreted as the estimator of a population parameter value. In order to construct an AOV for the AL and DL values, these variances were computed for each fabric and these values pooled to form a mean square error. The variance among the four fabrics' AL and DL values was also computed (Appendix H, Tables 6 & 8).

An analysis of variance done on the AL regression lines

for all four fabrics showed that there was a statistically significant difference among the slopes or b values ($p \leq .05$) (Appendix H, Table 4). A Least Squares Difference (LSD) post hoc comparison test was performed and showed that there was a significant difference between the regression lines of fabrics B and C ($p \leq .01$) and fabrics C and D ($p \leq .05$) (Appendix H, Table 5).

An analysis of variance done on the AL values of the four fabrics showed that there was no statistically significant difference. Although the AL regression lines of the four fabrics were significantly different (Fig. 16) the AL values were similar.

DIFFERENCE THRESHOLD

The percentage of "greater" responses of the stimulus pairs was computed for each subject by fabric and by stimulus intensity (see Appendix F). Ogive curves were demonstrated most of the time for all four fabrics.

Subject data were combined to determine the percentage of "greater" responses by fabric and by stimulus intensity. Again, the data were transformed using the probit function. The z scores were plotted on the Y axis against the variable stimulus intensities on the X axis using the method of least squares so that the psychometric function for each fabric could be observed (Figure 17).

Fig. 17 about here

After data transformation, all fabrics showed statistically significant linear relationships ($p \leq .01$) between responses and moisture. The percents of explained variation between the data points and the predicted lines for fabrics A, B, C, and D were 84%, 86%, 91%, and 79% (Table 3).

Table 3 about here

The Points of Subjective Equality (PSE) were determined by solving for x when z = 0 in equation 1. The PSE represents the value of the variable stimulus which over a large number of trials is perceived to be subjectively equal to the standard stimulus [6]. The PSEs determined for fabrics A, B, C, and D were: .078, .089 .069, and .089 ml, respectively. The standard stimulus for this study was .09 ml. It is interesting to note how close the PSEs for fabrics B and D are to the standard stimulus.

Comparing fabric A used in this study and Sweeney's study [19], the PSE values were .078 and .075 ml, respectively.

The constant error (CE) is the difference between the PSE and the standard stimulus and results from uncontrollable factors that often influence psychophysical results when successive presentations of stimuli are made to

two separate body locations [6]. The CEs determined for fabrics A, B, C, and D were: -.012, -.001, -.021, -.001 ml, respectively. The CE for fabric A in Sweeney's study [19] was -.015 ml. CEs occurred even though the order of stimulus presentations and the two body locations (right and left hands) were randomized.

The upper and lower difference thresholds (UT and LT) were determined for each fabric by solving for x when $z = \pm .67$ in equation 1. These z values represent the judgment that the variable stimuli were greater and less than the standard stimulus 25% and 75% of the time. The UTs for fabrics A, B, C, and D were determined to be .149, .135, .166, and .140 ml, respectively. The LTs for fabrics A, B, C, and D were determined to be .006, .043, -.029, .039 ml, respectively. The differences between the UT and LT values represent one difference threshold above and below the standard stimulus (.09 ml). This area between the UT and LT is known as the interval of uncertainty (IU) because within this range subjects cannot discriminate between the standard and variable stimuli.

The overall DL values were found by subtracting the LT from the UT and dividing by two [(UT - LT)/ 2]. The DL's for fabrics A, B, C, and D were determined to be .072, .046, .098, .051 ml, respectively. These DL values represent the amount of moisture difference needed in order for subjects to detect differences in moisture sensation when the standard stimulus was .09 ml.

The UT and LT values obtained in Sweeney's study [19] for fabric A were .114 ml and .037 ml, and the DL was .039 ml with stimulus detection from 18% to 85%. The large difference in the DLs of fabric A between the two studies is not quite understood, except that the slope of the line in Sweeney's study [19] was larger. Since these threshold values are derived from the intercept (a) divided by the slope (b) (Equation 2), a large slope (which is in the denominator) causes a smaller DL.

Fabric C had the largest DL value, meaning that for subjects to detect a difference in moisture sensation when the standard stimulus was .09 ml, the variable stimulus would have to differ in moisture by .098 ml. These calculations for fabric C should be interpreted cautiously for several reasons. Although a large amount of moisture is required to detect a difference most subjects perceived moisture in fabric C at a low moisture level. Perhaps there is easy and early detection of moisture with fabric C, but discrimination between different moisture levels is more difficult.

Additional testing is required so that a more complete stimulus value range can be determined. None of the fabrics covered the 1% to 99% range desired for statistically accurate DL values (see Table 3).

According to Weber's law, the difference between stimulus intensities must be increased by a constant fraction for a just noticeable difference (JND) to be

perceived. The relationship between the size of the DLs and the intensity level of stimulus is known as the Weber fraction and can be calculated using Equation 1, where each fabric's DL is divided by the standard stimulus value (.09 ml). The Weber fractions for fabrics A, B, C, and D were determined to be 79.4%, 51.1%, 108.3%, and 56.1% of the starting stimulus intensity at all intensity levels (Table 3; Appendix I, Fig. 18). Sweeney [19] found a Weber fraction of 42.7% for fabric A, as compared to 79.4% in this study. The size difference between these two Weber fractions is accounted for by the size difference between the DLs found in the two different studies. Sweeney's [19] DL value is small and thus yields a small Weber fraction.

The sizes of the Weber fractions correspond positively to the size of the DLs and negatively to the PSEs. The Weber fraction for fabric C should be interpreted cautiously. The JND steps are so large (and negative), quite unlike the other three fabrics (see Appendix I, Table 10 and Fig. 19). Fabrics B and D have much smaller JNDs, meaning it takes a much smaller change in stimulus intensity for a subject to perceive it. The size of the JNDs corresponds exactly with the size of the DL values.

An analysis of variance done on the DL regression lines for all four fabrics showed that there was no significant difference among the slopes or b values (Appendix H, Table 7). An analysis of variance was also performed on the DL values for all four fabrics and showed a statistically

significant difference ($p \leq .05$) (Appendix H, Table 8). An LSD post hoc comparison test was performed and showed that there were significant differences ($p \leq .05$) between fabrics A and B, fabrics C and A, C and B, and C and D (Appendix H, Table 9).

Although the DL regression lines of the four fabrics are very similar (Fig. 17), the DL values are different enough to be significantly different (Table 3). Subjects detected fabrics A, B, C, and D at similar enough moisture amounts that resulted in similar ALs. But discrimination between a variable and standard stimulus was much more difficult, and resulted in significantly different DLs.

The method and procedure of determining the DL could be a problem itself. This discrimination phase of the testing was notably more difficult for the subjects to accomplish. Two repetitions of AL and DL were performed at one session. One rep of DL took 15 to 20 minutes and was quite fatiguing for both the subjects and the investigator due to the great amount of concentration required. In addition, since subjects' hands were blotted only after removal of the second swatch (in the DL testing) the 3 to 5 second time period that the first hand sat empty, after just having a swatch removed, allowed air to contact the skin surface possibly causing evaporation of excess moisture.

Summary and Conclusions

Additional testing is required so that more accurate stimulus value ranges can be found for the DL's of the four fabrics used in this study. More testing is also required so that fabric C's stimulus values are more appropriate and demonstrate a psychometric function. Since thresholds are determined statistically, one should consider the limitations of the values found. These threshold values may not be a correct/accurate representation.

The difference between fabric A in this study and Sweeney's study [19] could be due to the extension of the range of stimulus intensities for both the AL and DL. However, the DL extension was still not enough because the stimulus range of responses is not as close to 1-99% as desired. Perhaps the standard stimulus intensity (.09 ml) should be changed. The physiological differences in body site between the dorsal region of the hand and back scapular region used by Sweeney [19] could also be a reason for the threshold differences because the body is not a uniform sensory surface [17].

Fabric B (100% cotton) and fabric D (double-sided fabric with 100% nylon side designed to be worn next to the skin) behaved very similarly in all testing. It follows that they were perceived similarly by subjects even though they are different in construction and fiber content.

In conclusion, fabric characteristics can influence moisture sensation when the psychophysical method of constant stimuli is used. The way in which humans sense moisture is not thoroughly understood because there are no special moisture sensing receptors or organs. However, studies show that moisture build-up within fabric layers can contribute to clothing discomfort [8, 9, 16]. In an effort to understand just how and to what degree moisture sensations influence clothing comfort, psychophysics provides an excellent way to quantify the relationship between moisture stimuli and the resulting sensation.

Implications of this work relating to clothing comfort are fascinating, yet they are premature and currently untested. When vapor pressure-time curves measured dynamic surface wetness of both inner and outer fabric surfaces the rate of changes in moisture concentration appeared to be initially faster with 100% polyester than with 100% cotton" [12]. Applying these findings to this study could be the reason for subjects sensing fabric C sooner than the other fabrics and having such a sharp detection function rather than a gradual one (as did fabrics B and D).

Remember that in the Hong et al. [12] study, the time curves leveled off after 30 minutes. In this study, after moisture application, swatches remained bottled for approximately 1 to 2 hours before their use. This time lapse could have allowed the vapor pressure to level off for the four fabrics--although this does not appear to be so.

Also, the environment the swatches were in was not dynamic, but at equilibrium. While bottling the fabric stimuli may not have stopped moisture (vapor or liquid) transfer within the fabric from occurring, it kept conditions more stable so that evaporation could not take place. Perhaps in the one to two hour time period, a vapor pressure equilibrium was reached.

In subjective comfort sensations, cotton is favored more than polyester under dynamic conditions. "Humans feel drier and more comfortable when vapor pressure at the inner fabric/clothing surfaces is low" [12, p. 704]. A slow rate of increase in moisture vapor pressure does not trigger uncomfortable sensations as strongly as does an abrupt change, and it also allows more time to adjust physiologically to the new exposure [12]. Relating this information to this study, perhaps fabric C would be judged uncomfortable in a scaled comfort test because moisture would be sensed very soon by subjects and would not allow for physiological adjustment. And perhaps fabric B would be judged comfortable in a scaled comfort test because moisture would be sensed very gradually by subjects and would allow more time to adjust physiologically. However, this study's results were obtained under equilibrium conditions rather than dynamic ones and comfort testing was not done, so no direct conclusions between clothing comfort and these psychophysical results can be drawn.

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TABLE 1

FABRIC CHARACTERISTICS

Fabric	Fiber Content	Weight (g/sq.m)	Yarn Count (cm)	Thick-ness (mm)	Construc-tion	Yarn Type and Twist	Fiber Type
A	50/50 cotton, polyester	149.88	Warp= 16 Weft= 14	.2337	plain	single Z twist	staple
B	100% cotton	211.26	Warp= 17 Weft= 13	.3848	plain	single Z twist	staple
C	100% ** polyester	139.64	Warp= 19 Weft= 17	.0889	plain	single Z twist	staple
D	100% nylon* 100% cotton*	187.00	Warp= 19 Weft= 17	.3696	double-knit	single 0 twist Z twist	filament staple

**Fabric C had a special four channel fiber engineered to promote wicking.
*Fabric D was a double-sided fabric with 100% nylon on the back side and 100% cotton on the front.

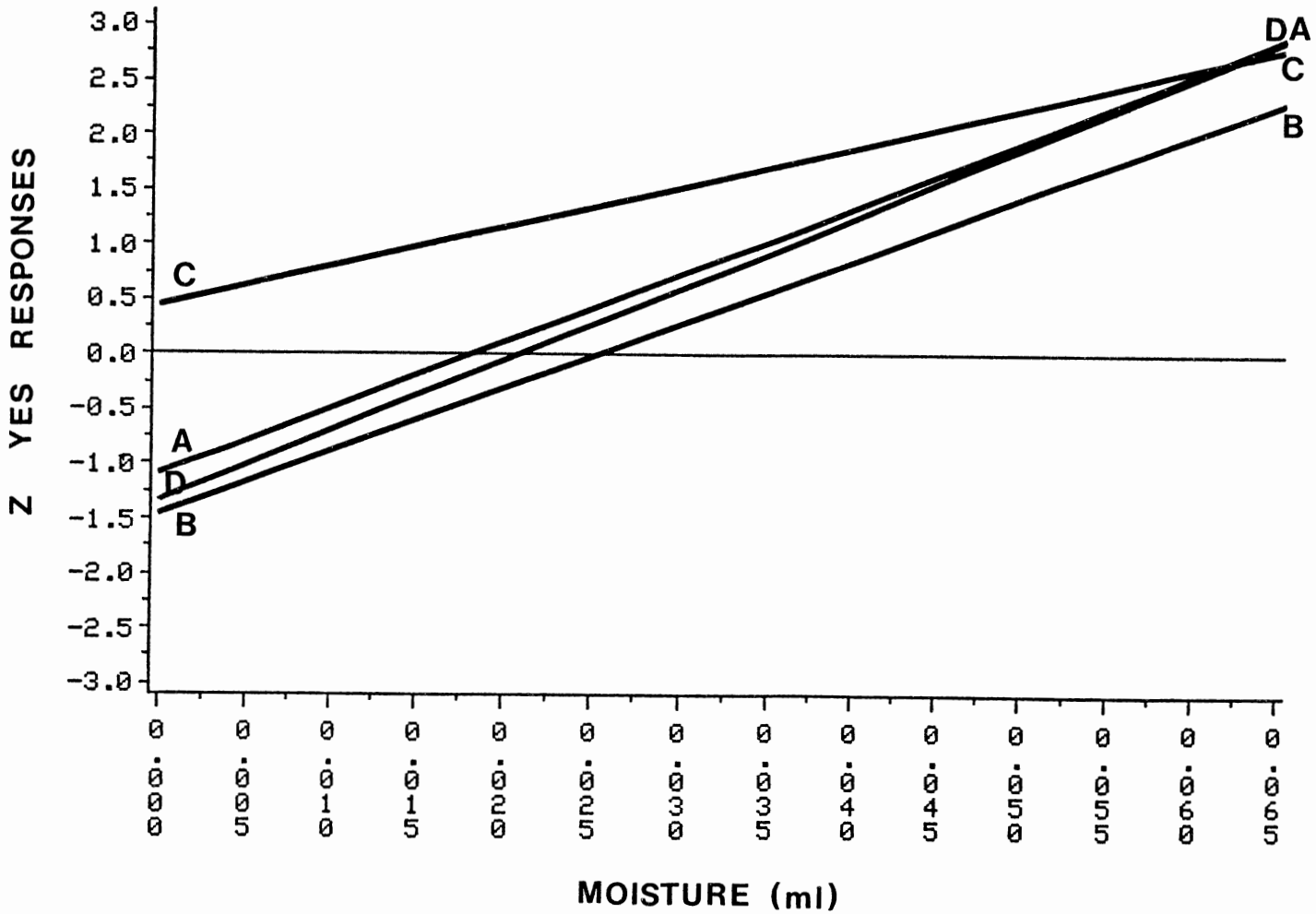

Figure 16. Psychometric Function for the Determination of the Absolute Threshold of Moisture Sensation.

TABLE 2

ABSOLUTE THRESHOLD OF MOISTURE SENSATION DATA

Fabric	AL	R^2	F-Value	Prob.>F	Range
A	.018	.82	27.593	.0019	1.8%-99%
B	.025	.97	166.596	.0001	7.0%-98%
C	-.012	.37	3.522	.1096	3.6%-99%
D	.021	.84	31.658	.0013	1.0%-99%

*DF = 1,6

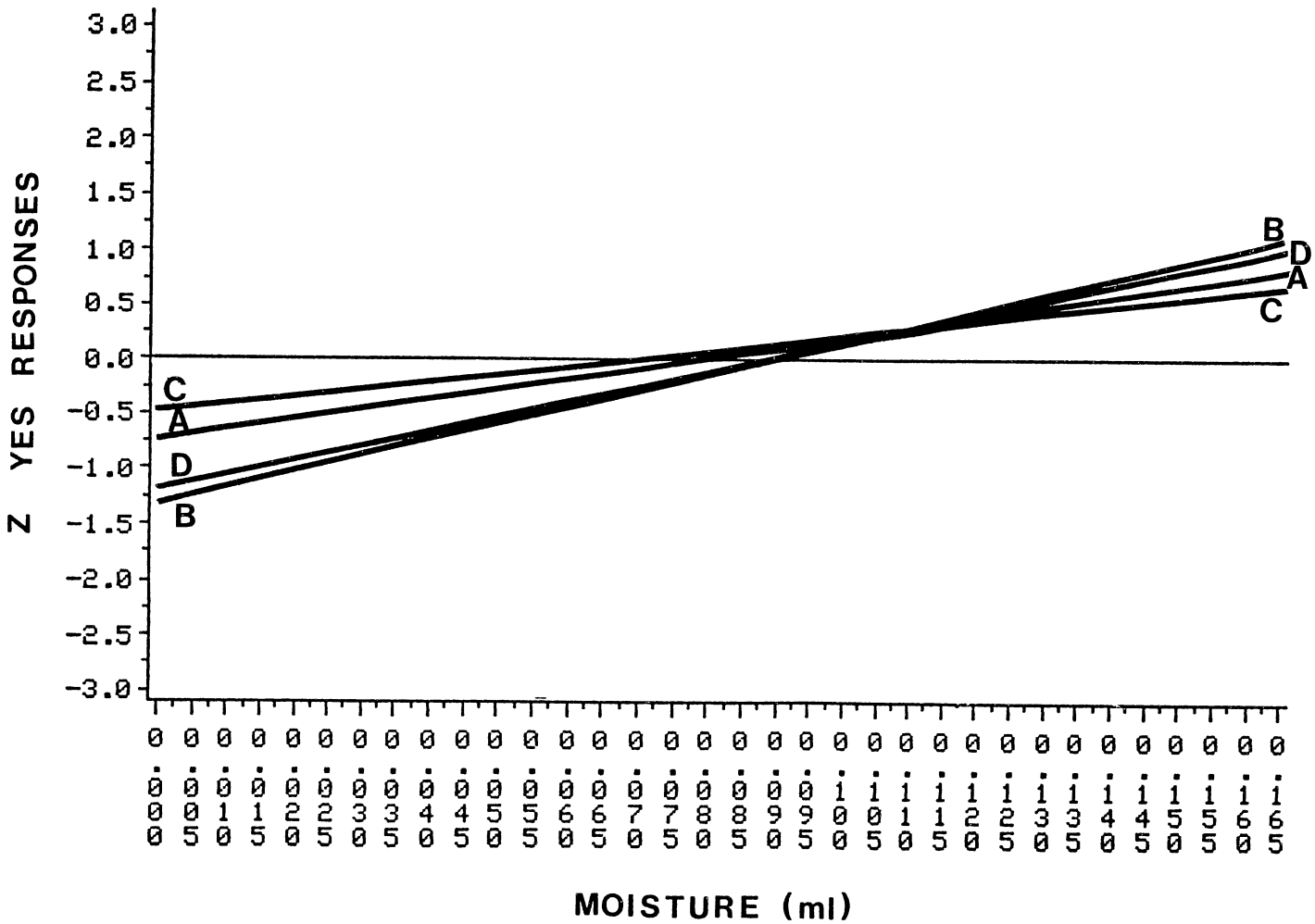

Figure 17. Psychometric Function for the Determination of the Difference Threshold of Moisture Sensation.

TABLE 3

DIFFERENCE THRESHOLD OF MOISTURE SENSATION DATA

Fabric	R^2	F-Value	Prob.>F	PSE	CE	UT	LT
A	.84	26.031	.0038	.078	-.012	.149	.006
B	.86	31.621	.0025	.089	-.001	.135	.043
C	.91	50.070	.0009	.069	-.021	.166	-.029
D	.79	18.488	.0077	.089	-.001	.140	.039

*DF = 1,5
**PSE, CE, UT, LT, DL values all in ml

TABLE 3 (Continued)

Fabric	DL	Range	Weber Fraction
A	.072	17.9%-73.2%	79.4%
B	.046	5.5%-85.5%	51.1%
C	.098	30.4%-73.2%	108.3%
D	.051	5.5%-81.8%	56.1%

*DF = 1,5
**PSE, CE, UT, LT, DL values all in ml

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

Clothing comfort is a most interesting phenomena. Because it is so complex and dynamic researchers in all disciplines involved do not agree on one definition of it. A recent definition of clothing comfort generally defines it as "a state of satisfaction indicating physiological, psychological and physical balance among the person, his/her clothing, and his/her environment" (Branson & Sweeney, 1987, p. 14).

The most common method in assessing clothing comfort in the past has been psychological scaling techniques. A problem with these different scales is that they often produce different results. Heat exchange must occur through clothing to ensure the body's proper heat balance with the environment (Mecheels & Umbach, 1977; DeMartino, Yoon, Buckley, Evins, Averell, Jackson, Schultz, Becker, Booker, & Hollies, 1984). When moisture sensations are evoked a garment wearer may become dissatisfied or uncomfortable with that garment. Moisture build-up on the skin, in the microclimate, and within garment layers is a critical

problem in functional apparel and athletic or protective gloves. Moisture moves through and is held by fabrics differently, this may be the key factor to understanding how moisture sensation is related to clothing comfort.

The purpose of this study was to use the psychophysical method of constant stimuli to investigate the influence of fabric on threshold determinations of moisture sensation. The hand was chosen as the test site because it is an area where glove liner fabric has high contact with the skin. Psychophysics can quantitatively assess the relationship between physical stimuli and psychological sensations. Psychophysical methods may apply to many clothing comfort sensations, but were only applied to moisture sensation in this study.

Objectives

This research was guided by two objectives. The first was to use the psychophysical method of constant stimuli to determine the absolute and difference thresholds (AL, DL) of moisture sensation in one body location using four selected fabrics. The AL is the minimum value of a physical stimulus that will evoke a sensation. The DL is the minimum amount of physical stimulus change required to produce a perceived sensation difference. The second objective was to explore how fabric characteristics influenced these threshold determinations.

Test Facility and Subjects

Testing was conducted in an environmentally controlled chamber with conditions at 26° ± 2°, 50% RH ± 2%, and air movement of less than .15 m/s. These conditions are considered thermally comfortable for a subject lightly clothed and at rest (ASHRAE, 1981). All subjects were pre-tested for moisture sensitivity before being allowed to participate in the study. No subjects were eliminated through pre-testing. Fifteen college females, ages 19 to 23, participated in the study. Subject six's responses did not follow the same pattern as the other fifteen subjects, therefore it was decided not to include subjects six's data in the data analyses. It should be noted that subject six was the largest subject in physical size, indicating that physical size may make a difference in moisture sensation.

Fabric Stimuli

Swatches of fabrics A, B, C, and D measuring 5 X 5 cm were used as the physical stimuli. All fabrics were suitable to be worn next to the skin as lightweight T-shirts. Fabric A was a 50/50 cotton/polyester blend, fabric B was a 100% cotton, fabric C was a 100% polyester with a special four channel fiber shape, and fabric D was a double-sided fabric with a 100% specialty nylon on the back side and a 100% cotton on the front.

Testing

Absolute Threshold. Fabric swatches contained eight different moisture amounts as follows: .000, .005, .015, .025, .035, .045, .055, .065 ml. Presentation of stimuli was randomized and subjects responded "yes" or "no" as to whether they detected moisture or not. Four replications were completed.

Difference Threshold. Fabric swatches contained seven variable moisture amounts as follows: .015, .040, .065, .090, .115, .140, .165 ml. The .090 ml stimulus value served as the standard stimulus to which each of the variable stimuli were compared. Presentation of stimuli was randomized and subjects responded to the question--"Was the variable stimulus "greater" or "less" than the standard stimulus in wetness".

Results

Absolute Thresholds. The AL of moisture sensation is the minimum value of a physical stimulus that will evoke a sensation. Operationally it is the stimulus value that is detected 50% of the time (Gescheider, 1976). The ALs for fabrics A, B, C, and D were determined to be .018, .025, -.012, .021 ml, respectively. Fabrics A, B, and D exhibited psychometric functions as predicted by psychophysical theory, but fabric C did not.

An AOV done on the AL regression lines for all four fabrics showed significant differences between the slopes of the lines ($p \leq .05$) and an LSD post hoc comparison test showed that there were significant differences between fabrics B and C ($p \leq .01$) and fabrics C and D ($p \leq .05$). An AOV done on the AL values of the four fabrics showed no significant difference.

Difference Thresholds. Variable stimulus values judged "greater"or "less" than the standard stimulus (.090 ml) 25% and 75% of the time were averaged to give the DL of moisture sensation (Gescheider, 1976). The DLs for fabrics A, B, C, and D were determined to be .072, .046, .098, .051 ml, respectively. All four fabrics exhibited psychometric functions as psychophysical theory predicts. An AOV done on the DL regression lines of the four fabrics showed no significant difference between the slopes of the lines. An AOV done on the DLs of the four fabrics showed that there was a significant difference ($p \leq .05$). An LSD test showed that there were significant differences between fabrics A and B, C and A, C and B, and C and D (all $p \leq .05$).

Weber's law predicts that the size of the DL is a linear function of stimulus intensity (Gescheider, 1976). Weber fractions were found by dividing the DL by the standard stimulus value (.090 ml), and were determined for fabrics A, B, C, and D to be 79.44%, 51.11%, 108.33%, 56.11% of the starting stimulus intensity at all intensity levels.

Implications

The findings of this study have implications for researchers interested in the phenomena of clothing comfort. However, a direct link between clothing comfort and the psychophysical results obtained in this study would be premature because these fabrics were not comfort tested.

In all but one instance, subjects' judgmental responses to wetted fabric stimuli followed a linear trend between subjects' responses and moisture that is also found for other sense modalities. Threshold values for moisture sensation can be assessed by the psychophysical method of constant stimuli. However, additional testing is required so that more accurate stimulus value ranges can be found for DL and so that the stimulus values for fabric C are more appropriate resulting in positive AL and a proper psychometric function.

Fabric characteristics do appear to influence threshold determinations of moisture sensation. Fabric C, the 100% polyester, stands out as the most different of the four fabrics because of its having a negative and the lowest AL value and the highest DL value. Table 1 shows that fabric C is the thinnest, lightest-weight fabric with a special four channel fiber designed to wick. Fabric C was perceived as wet at .005 ml of moisture. This low value led the investigator to wonder if wicking actually occurred at all. In addition, fabric C had the smoothest inner and outer

fabric surfaces allowing it to contact the skin more closely.

In contrast, fabric B, the 100% cotton, has the highest AL value and lowest DL value. Table 1 shows that fabric B is the thickest, heaviest-weight fabric which also had the roughest/hairiest inner and outer fabric surfaces. Fabric B was perceived very gradually. In addition, fabric D behaved very similarly to fabric B though their construction and fiber content were different.

Recommendations

1. It is recommended that future work move toward examining moisture sensitivity using different areas of the body, fabric stimuli, and moisture values.

2. It is recommended that different environmental conditions be studied so that the impact of the environment on moisture sensation will be more clearly understood.

3. It is recommended that the sensory mechanisms for moisture sensation be studied so that we will understand how humans perceive moisture.

4. It is recommended that a study be conducted to examine the influence of physical size on moisture sensation. Age and sex could also be manipulated.

5. It is recommended that fabric C be examined in various

thicknesses and with various moisture levels so that a more accurate and understandable AL value could be obtained.

6. It is recommended that psychophysical testing be coupled with comfort testing using psychological scaling techniques so that moisture sensation, as it relates to comfort or discomfort, will be better understood.

Limitations

1. Female students were recruited and paid $30.00 total for their participation. The method of acquisition of the sample and the amount of the monetary payment may have influenced the subjects' responses. Limitations of sex, age, and body size do not allow the results to be generalized to other populations.

2. This study was limited to one body site (back of hand) and four fabrics. Since the skin is not a uniform sensory surface, sensitivity may be affected by stimulus intensity, location of stimulation, and duration of the stimulation. In this regard, findings can not be generalized to other body areas, other fabric stimuli, size of stimuli, or other durations of stimulation not used in this study.

3. The AL and DL values of moisture sensation were determined for each fabric even though the responses to the moisture stimuli did not, in all cases, fully capture the range from a little more than 0% to a little less than 100%.

The psychophysical literature requires this response range (about 1% to 99%) for accurate determination of threshold values. Therefore, the threshold values obtained in this study that did not capture this complete 1% to 99% range may not be psychophysically accurate.

4. The AL of moisture sensation was determined for each fabric even though it was a negative value for fabric C and fabric C did not significantly demonstrate a psychometric function as did the other fabrics.

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APPENDIXES

APPENDIX A

INFORMED CONSENT

INFORMED CONSENT

I, _____, voluntarily agree to participate in this study entitled: Influence of Fabric on Threshold Determinations for Moisture Sensation which is sponsored by Home Economics Research through the Department of Clothing, Textiles & Merchandising, Oklahoma State University.

I understand that the purpose of this study is to investigate the influence of fabric on moisture sensation in individuals, and that testing will involve swatches of four different fabrics, wetted with water, that will be applied to the back/top of my hand.

I understand that the procedure for assessing moisture sensation will require my participation in the following ways:

1. Pre-testing: (1/2 hour approximately) All subjects will be pre-tested to determine sensitivity to moisture. An area on the back of the hand will be mapped by placing 1/2 X 1/2 inch swatches of fabric A wetted with .10 ml of water onto the hand. The fabric will be placed randomly. Occasionally a dry swatch will be presented. After a five second application of the fabric swatch, the subject will be asked to respond "yes" or "no" to the posed question: "Do you detect the presence of moisture on your hand?". This grid pattern assessment will determine those subjects who will be allowed to participate in the rest of the study.

2. Testing: (3 hours approximately) In the first part, 2 X 2 inch swatches of fabrics A, B, C, and D will be wetted with various amounts of water and placed alternately on the subject's left and right hands (exact location to be determined by mapping). Subjects will be asked to respond to the same question as in the pre-testing. In the second part of testing, a comparison between swatches, placed alternately on opposing hands at different times for the same time period of five seconds, will be made by the subject. The posed question will be: "Does the amount of moisture on the left (right) feel greater or less than the amount on the right (left)?", to which the subject will respond "greater" or "less".

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

1. knowledge of, and experience in, sensory testing,
2. payment of $5.00 for participation in the pre-testing,
3. payment of $25.00 for participation in the entire study (in addition to the $5.00 for pre-testing).

I understand that there are no risks anticipated by the investigators for participants in this study and that records of this study will be kept confidential with respect to verbal reports making it impossible to identify me individually. I also understand that I can withdraw from this study at any time without negative consequences.

I have read this informed consent document and understand its contents. I am a female, age 19-23, and 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 Signature of the Research Subject

_____ _____
Date/Time Signature of the Witness

_____ _____
Date/Time Signature of the Principal Investigator

I may contact Dr. Donna Branson at telephone number (405) 744-5035 should I wish further information regarding this research. I may also contact Terry Maciula, University Research Services, 001 Life Sciences East, Oklahoma State University, Stillwater, OK 74078, telephone number (405) 744-5700.

APPENDIX B

PAYMENT FORM

PAYMENT FORM

Invoice

Dr. Donna Branson, Professor
Clothing, Textiles & Merchandising
309 Home Economics West
(405) 744-5035

Date:_____

Invoice #:_____

Date(s)	Service(s) Performed	Payment

Name (print):_____

Social Security Number:_____

Permanent or Home Address:_____
City/State/Zip:_____

Local Telephone Number:_____

Are you currently on any OSU payroll? _____NO
_____YES

If yes, _____wage
_____salary

Total Payment Due:_____

Signature:_____

Received By:_____

APPENDIX C

PRE-TEST DATA SHEET

PRE-TEST DATA SHEET

Subject_____
Handedness_____
Date_____
Time_____

MAPPING/PRE-TEST

20 swatches of fabrics A. B, C, & D (5 each). Some wetted with .10 ml of water (about 16) and some (about 4) completely dry. Question: "Do you detect moisture?" Mark box with a "+" if "yes" and a "--" if no. If the swatch is dry and the subject detects moisture, mark box with a "*".

RIGHT HAND

LEFT HAND

COMMENTS:

APPENDIX D

AL AND DL DATA SHEETS

AL DATA SHEET

Subject_____ Date_____
Handedness_____ Time_____

AL: Question: "Do you detect moisture?" Place a "Y" to the right of the stimulus amount if response is "yes" and a "N" if "no". Alternate hands.

REP 1
Fabric-Hand

A--Rt	.025	.005	.055	.035	.065	.045	.015	.00
B--Lt	.035	.015	.045	.055	.00	.005	.065	.025
C--Rt	.015	.065	.035	.005	.025	.055	.00	.045
D--Lt	.00	.055	.025	.045	.035	.065	.005	.015

REP 2

B--Rt	.025	.005	.055	.035	.065	.045	.015	.00
C--Lt	.035	.015	.045	.055	.00	.005	.065	.025
D--Rt	.015	.065	.035	.005	.025	.055	.00	.045
A--Lt	.00	.055	.025	.045	.035	.065	.005	.015

Date_____ Time_____

REP 3
Fabric-Hand

C--Rt	.025	.005	.055	.035	.065	.045	.015	.00
D--Lt	.035	.015	.045	.055	.00	.005	.065	.025
A--Rt	.015	.065	.035	.005	.025	.055	.00	.045
B--Lt	.00	.055	.025	.045	.035	.065	.005	.015

REP 4

D--Rt	.025	.005	.055	.035	.065	.045	.015	.00
A--Lt	.035	.015	.045	.055	.00	.005	.065	.025
B--Rt	.015	.065	.035	.005	.025	.055	.00	.045
C--Lt	.00	.055	.025	.045	.035	.065	.005	.015

COMMENTS:

DL DATA SHEET

Subject_____ Date_____
Handedness_____ Time_____

DL: Question: "Was the variable stimulus greater or less than the standard stimulus?" Place a "G" to the right of the stimulus amount if response is "greater" and "L" if "less" than. Alternate hands and the order of presentation of the standard stimulus.

**Standard stimulus = .09 ml

REP 1

Fabric-Hand-S							
A--Rt--St	.115	.165	.065	.015	.090	.140	.040
B--Lt--Sv	.090	.140	.015	.165	.040	.065	.115
C--Rt--Sv	.040	.015	.115	.090	.065	.165	.140
D--Lt--St	.065	.040	.165	.140	.115	.015	.090

REP 2

B--Rt--St	.115	.165	.065	.015	.090	.140	.040
C--Lt--Sv	.090	.140	.015	.165	.040	.065	.115
D--Rt--Sv	.040	.015	.115	.090	.065	.165	.140
A--Lt--St	.065	.040	.165	.140	.115	.015	.090

Date_____ Time_____

REP 3

Fabric-Hand-S							
C--Rt--St	.115	.165	.065	.015	.090	.140	.040
D--Lt--Sv	.090	.140	.015	.165	.040	.065	.115
A--Rt--Sv	.040	.015	.115	.090	.065	.165	.140
B--Lt--St	.065	.040	.165	.140	.115	.015	.090

REP 4

D--Rt--St	.115	.165	.065	.015	.090	.140	.040
A--Lt--Sv	.090	.140	.015	.165	.040	.065	.115
B--Rt--Sv	.040	.015	.115	.090	.065	.165	.140
C--Lt--St	.065	.040	.165	.140	.115	.015	.090

COMMENTS:

APPENDIX E

QUESTIONNAIRE

QUESTIONNAIRE

SUBJECT # _____

Handedness:_____

Age: _____

Height: ____ft. ____in. (round up to nearest inch)

Weight: _____

Year in College (circle): FR SO JR SR GR OTHER

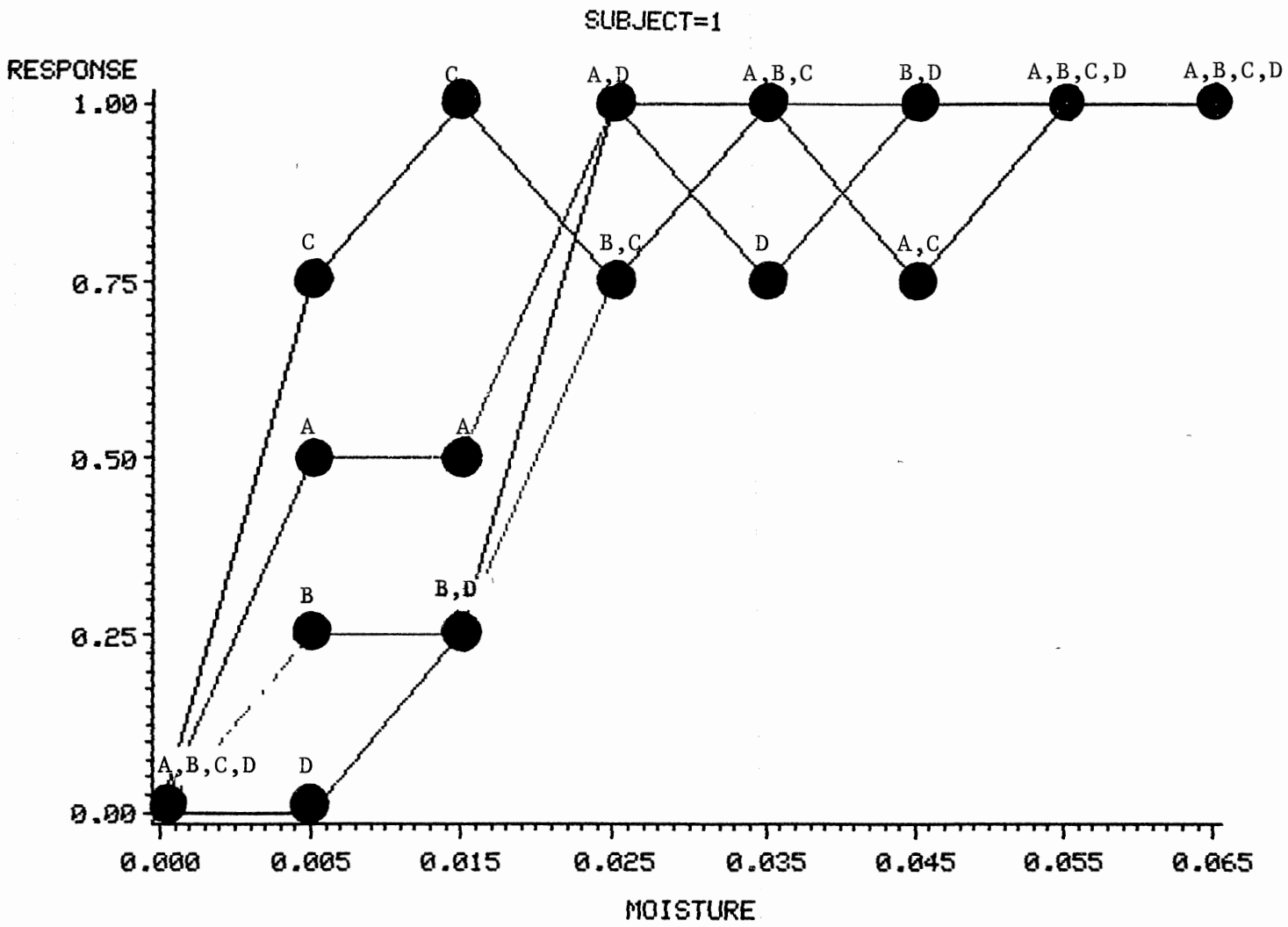
Are there any particular fibers or fabrics which you avoid wearing?

YES____ NO____

If YES, which ones (circle):
100% cotton
50% cotton, 50% polyester
100% polyester
100% wool
100% acrylic
100% nylon
Lycra blend
Other _____

APPENDIX F

AL RAW DATA BY SUBJECT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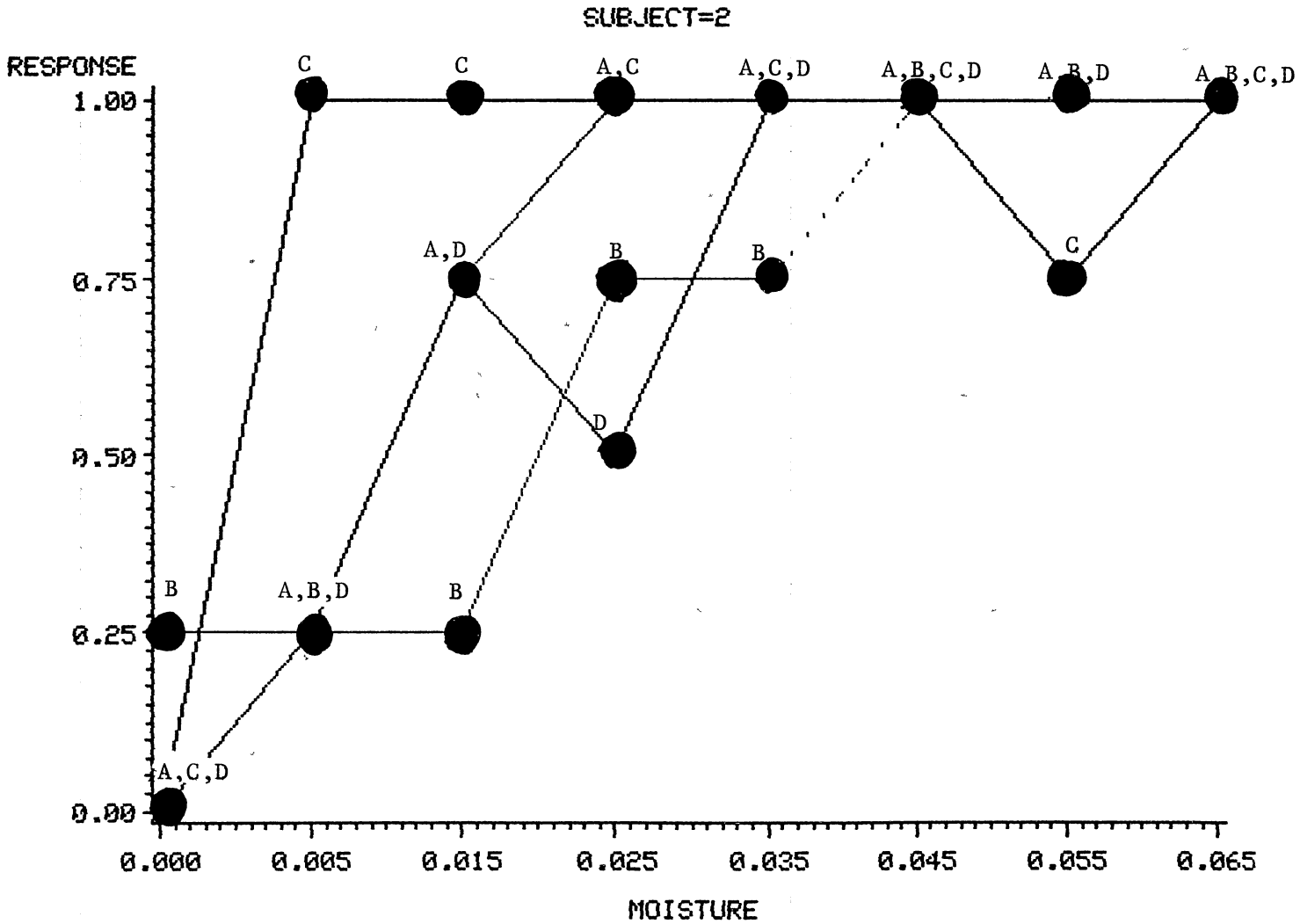
RESPONSE
1.00
0.75
0.50
0.25
0.00
C
A,D
A,B,C
B,D
A,B,C,D
A,B,C,D
C
B,C
D
A,C
A
A
B
B,D
A,B,C,D
D
0.000
0.005
0.015
0.025
0.035
0.045
0.055
0.065
MOISTURE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RESPONSE
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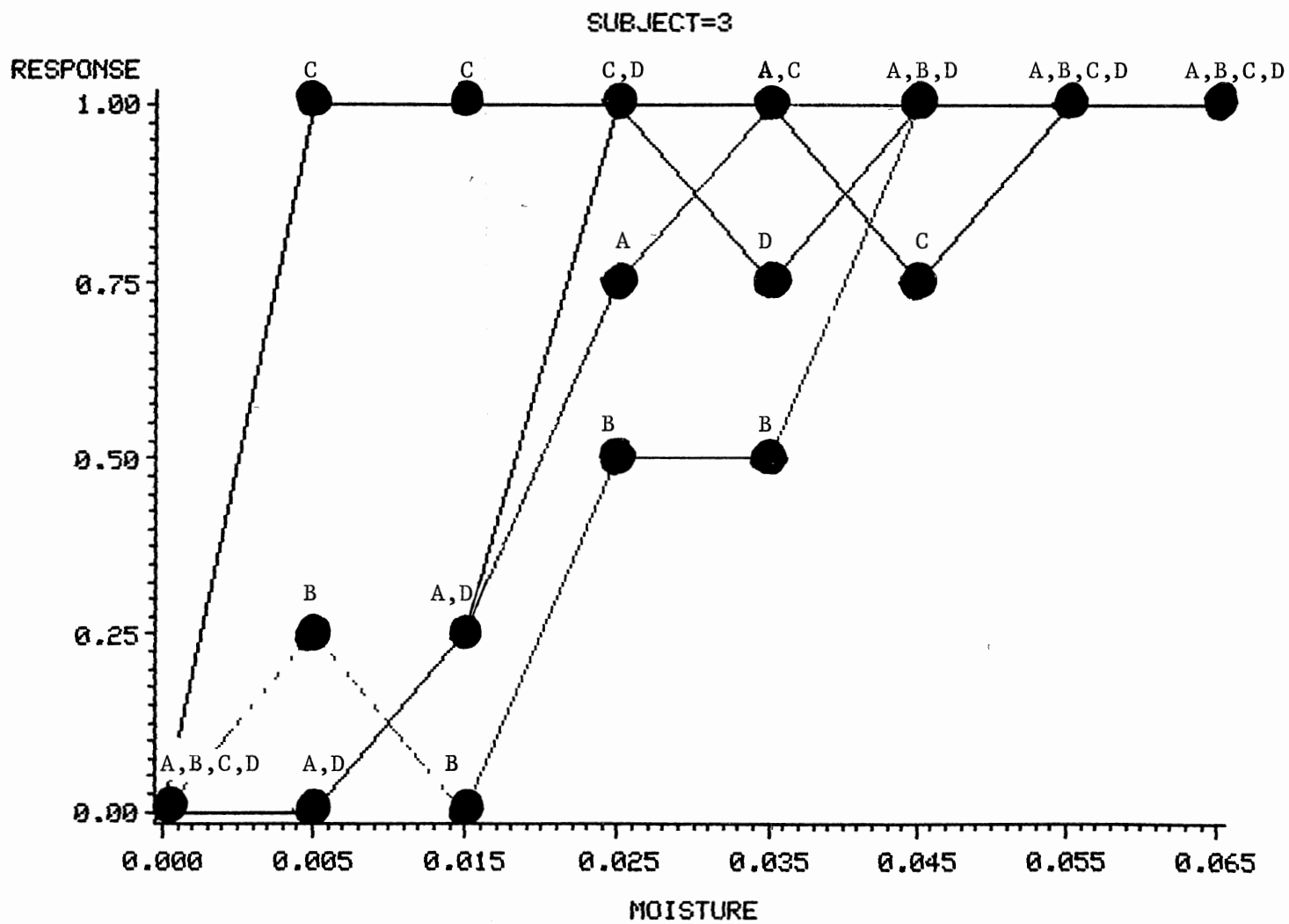
0.75
0.50
0.25
0.00
C
C
A,C
A,C,D
A,B,C,D
A,B,D
A,B,C,D
A,D
B
B
C
D
B
A,B,D
B
A,C,D
0.000
0.005
0.015
0.025
0.035
0.045
0.055
0.065
MOISTURE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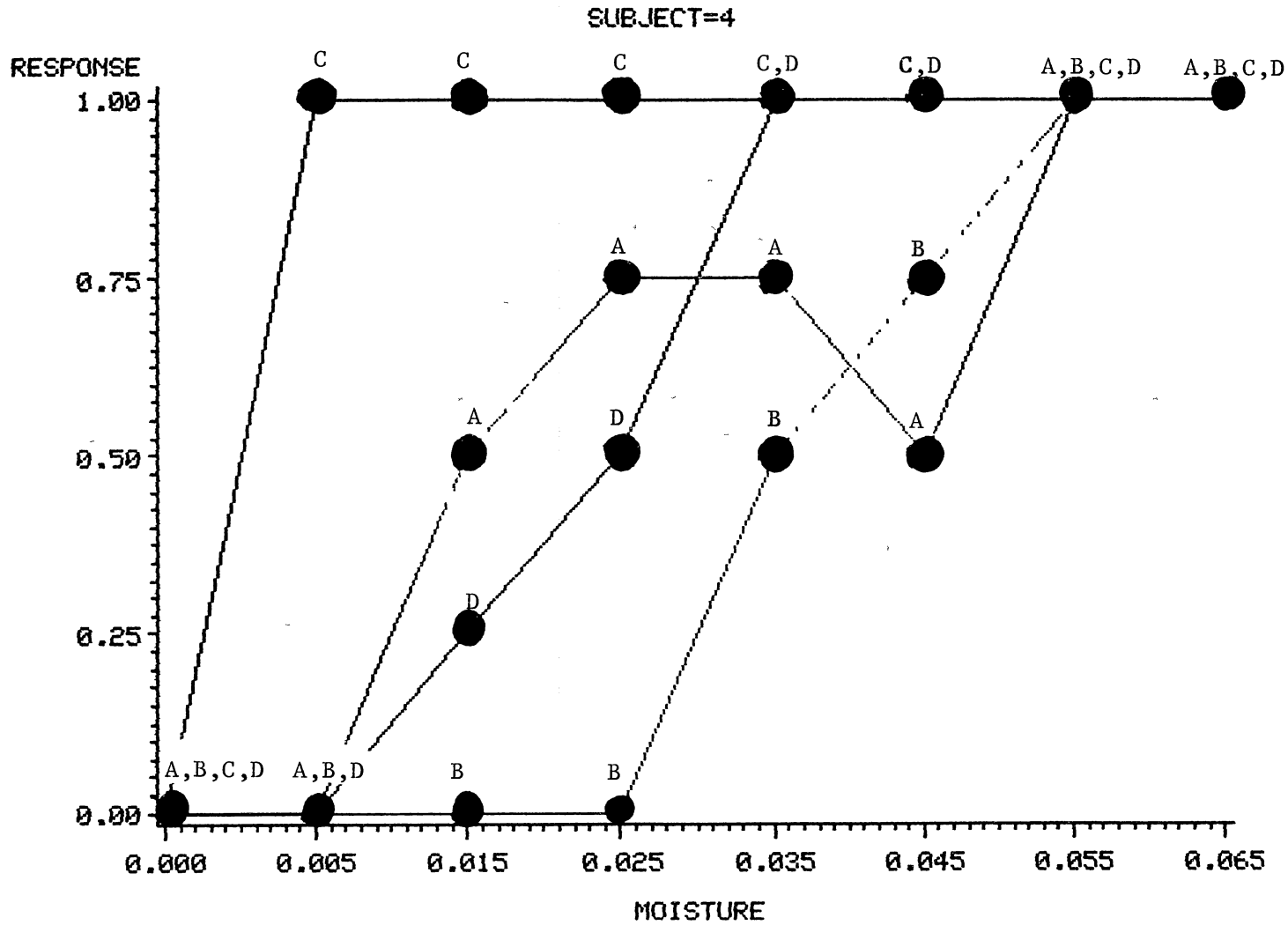
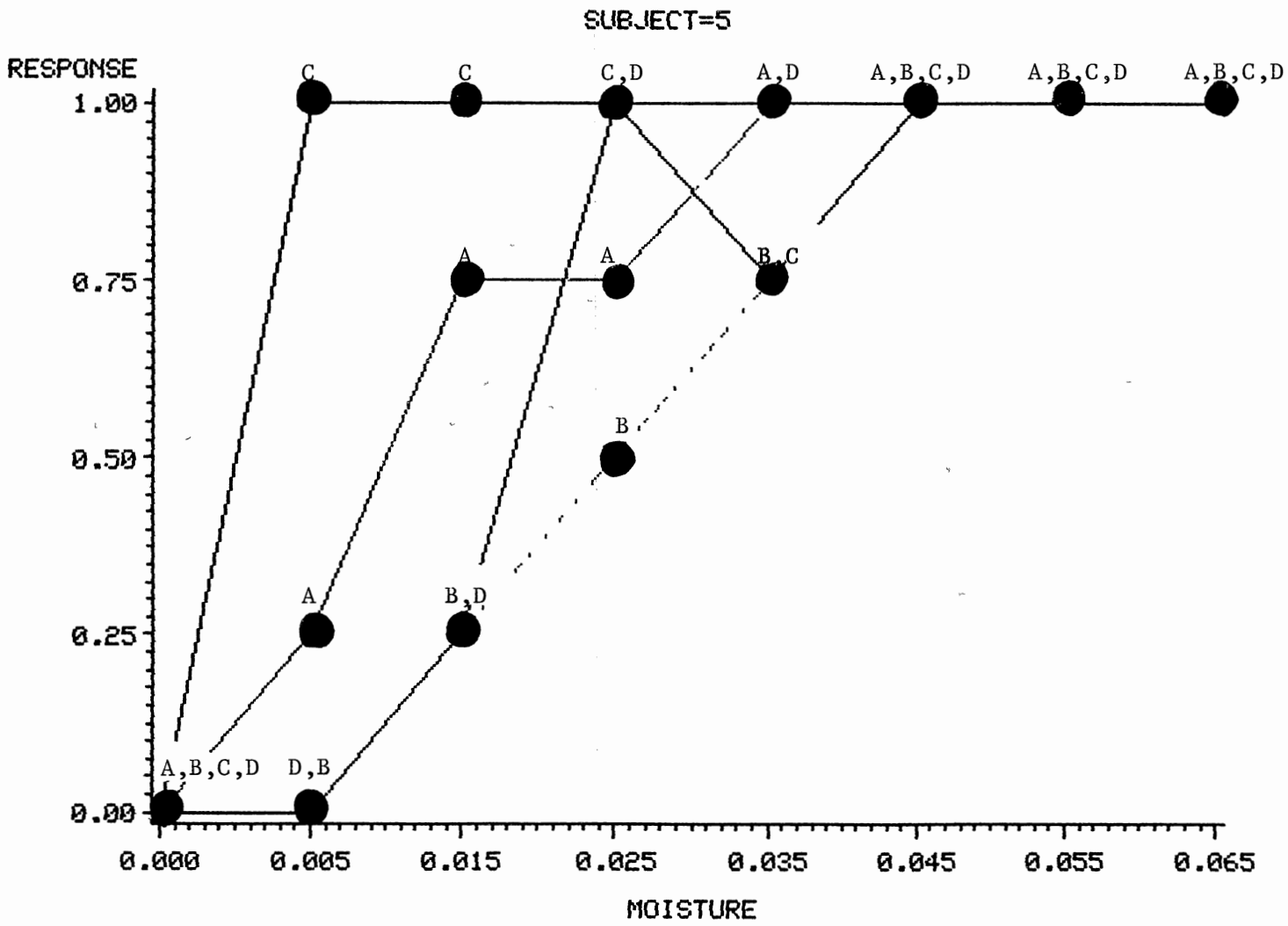
RESPONSE
1.00
0.75
0.50
0.25
0.00
C
C
C,D
A,C
A,B,D
A,B,C,D
A,B,C,D
A
D
C
B
B
B
A,D
A,B,C,D
A,D
B
0.000
0.005
0.015
0.025
0.035
0.045
0.055
0.065
MOISTURE


SUBJECT=4
RESPONSE
1.00
0.75
0.50
0.25
0.00
C
C
C
C,D
C,D
A,B,C,D
A,B,C,D
A
A
B
A
D
B
A
D
A,B,C,D
A,B,D
B
B
0.000
0.005
0.015
0.025
0.035
0.045
0.055
0.065
MOISTURE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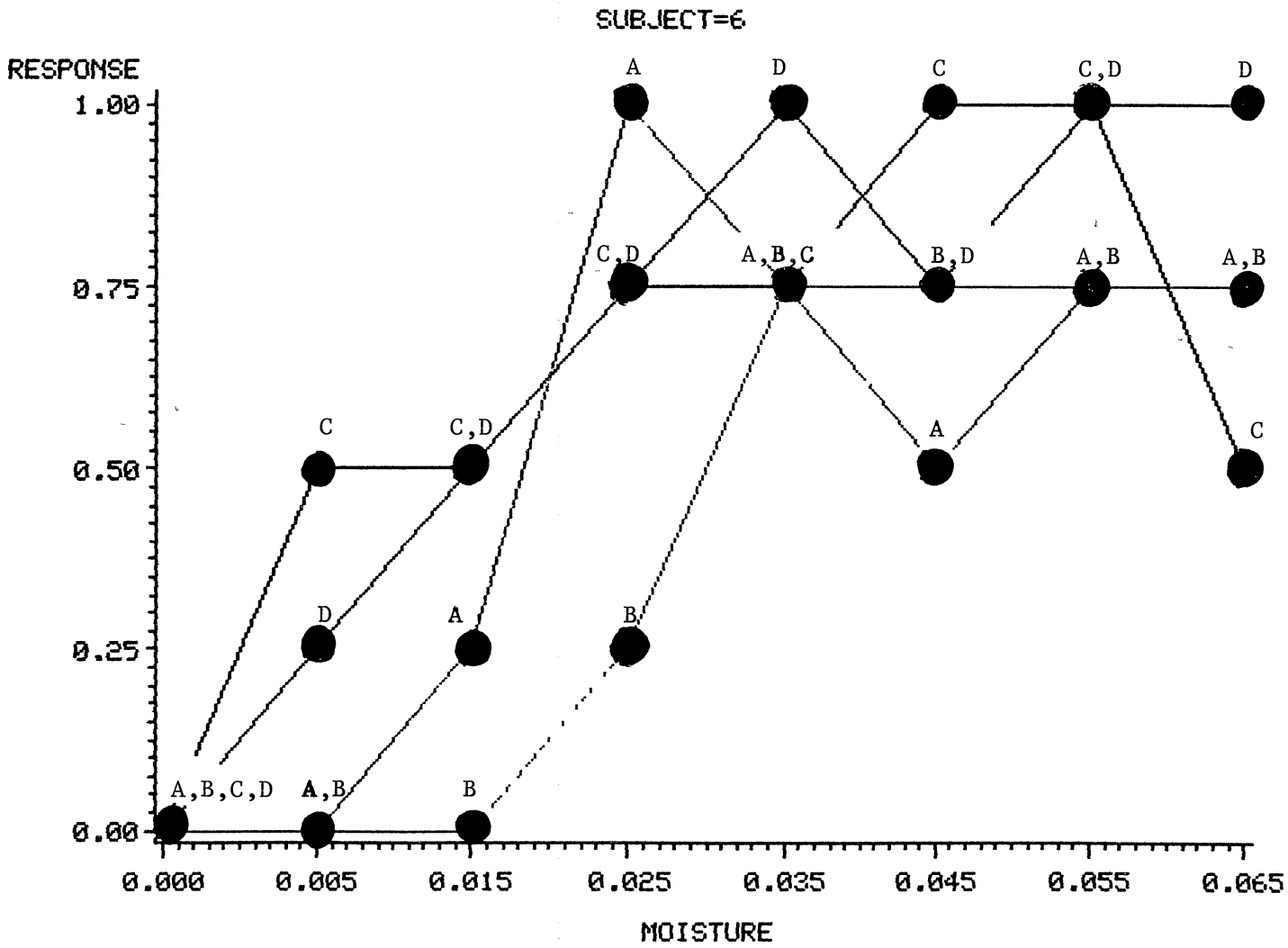
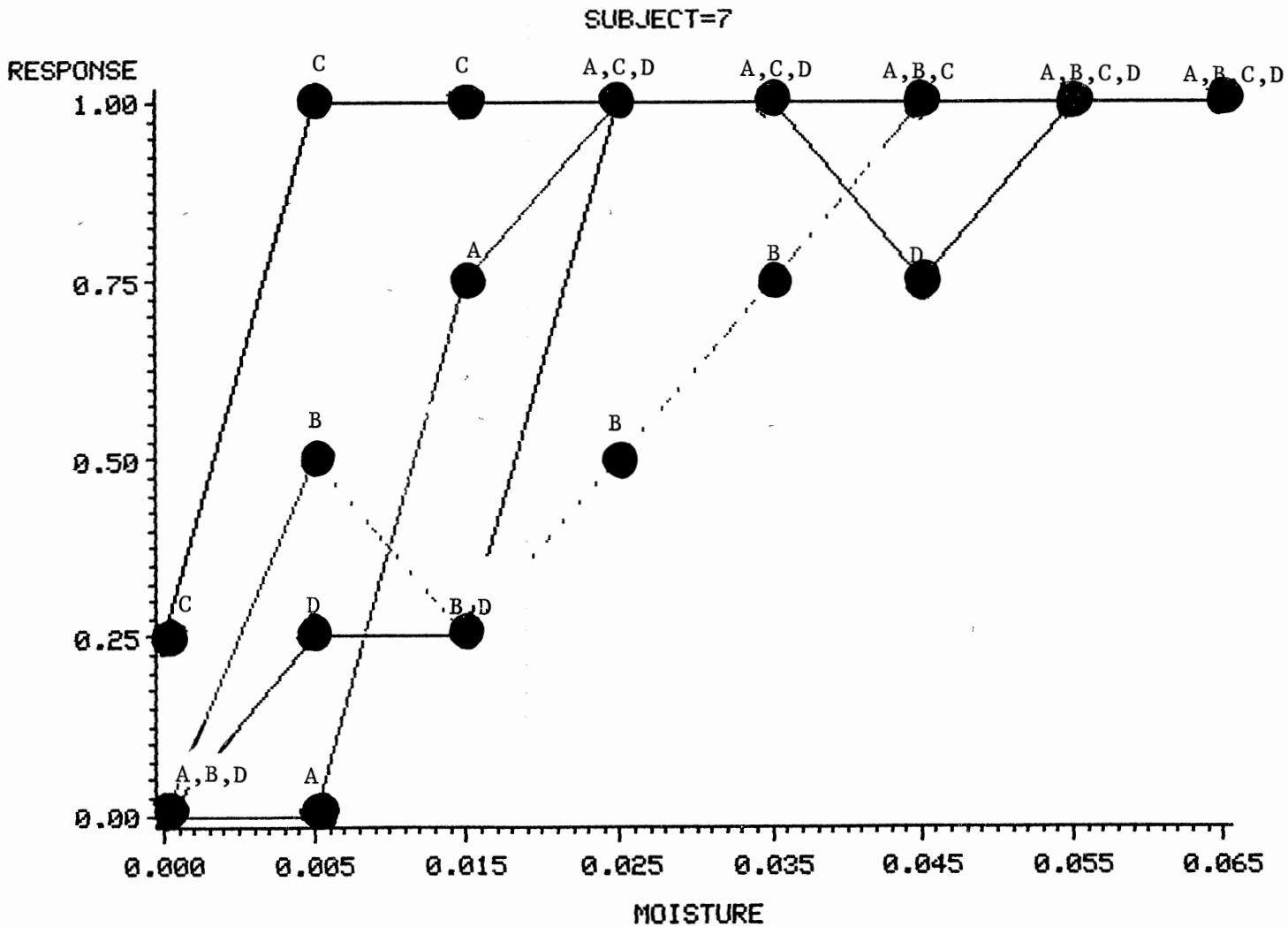
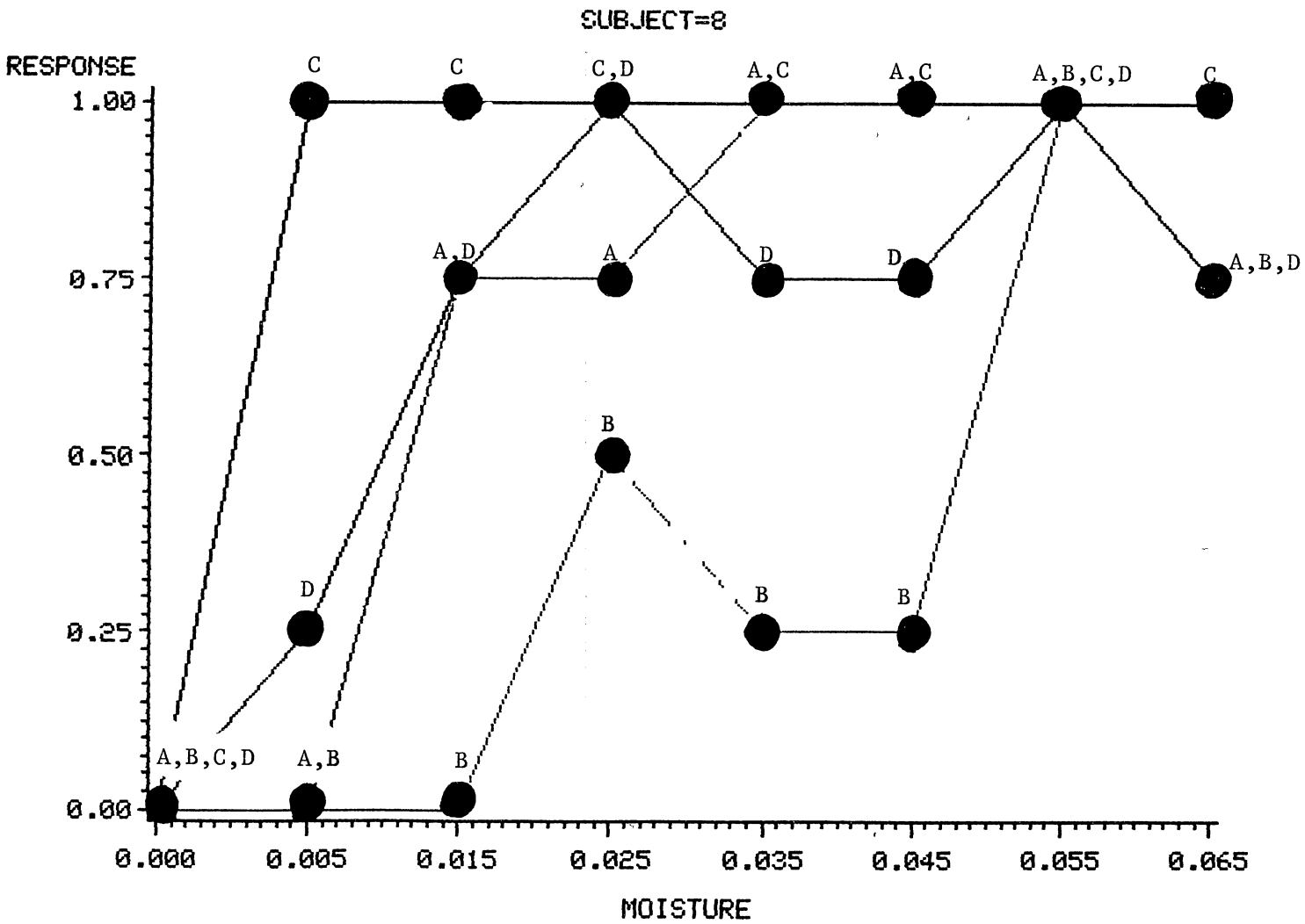
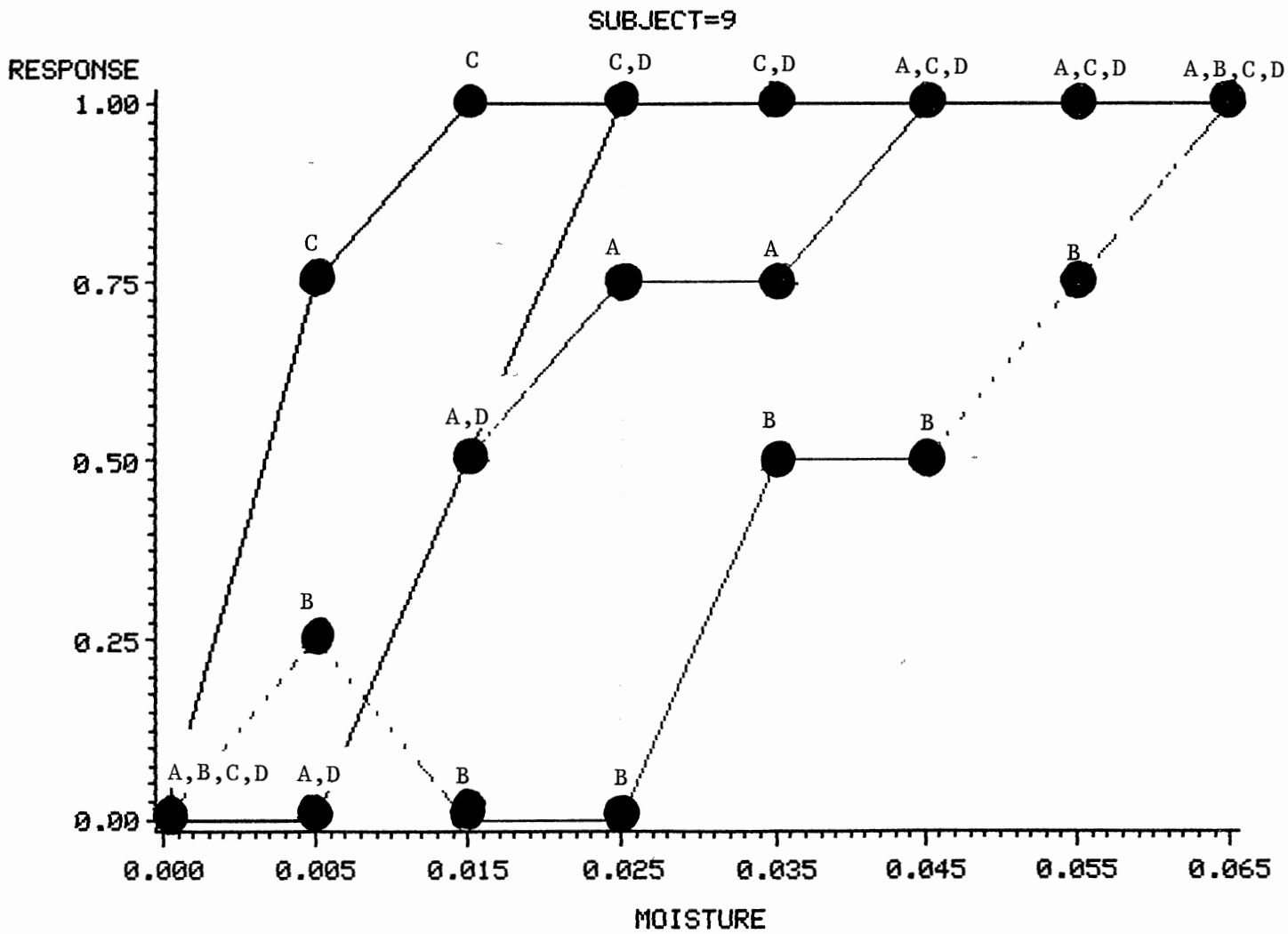
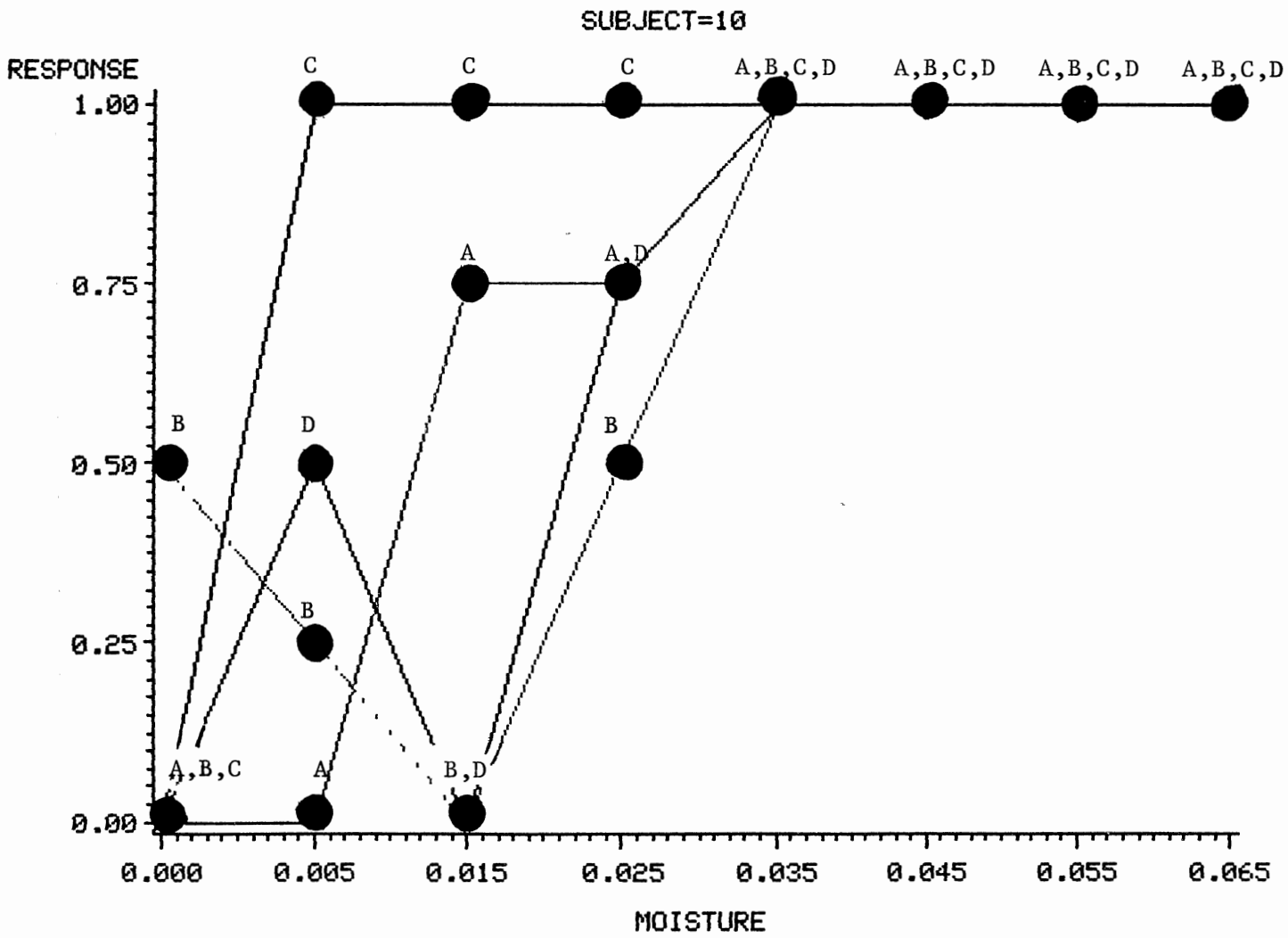
RESPONSE
1.00
0.75
0.50
0.25
0.00
C
C
C,D
A,D
A,B,C,D
A,B,C,D
A,B,C,D
A
A
B,C
B
A
B,D
A,B,C,D
D,B
0.000
0.005
0.015
0.025
0.035
0.045
0.055
0.065
MOISTURE

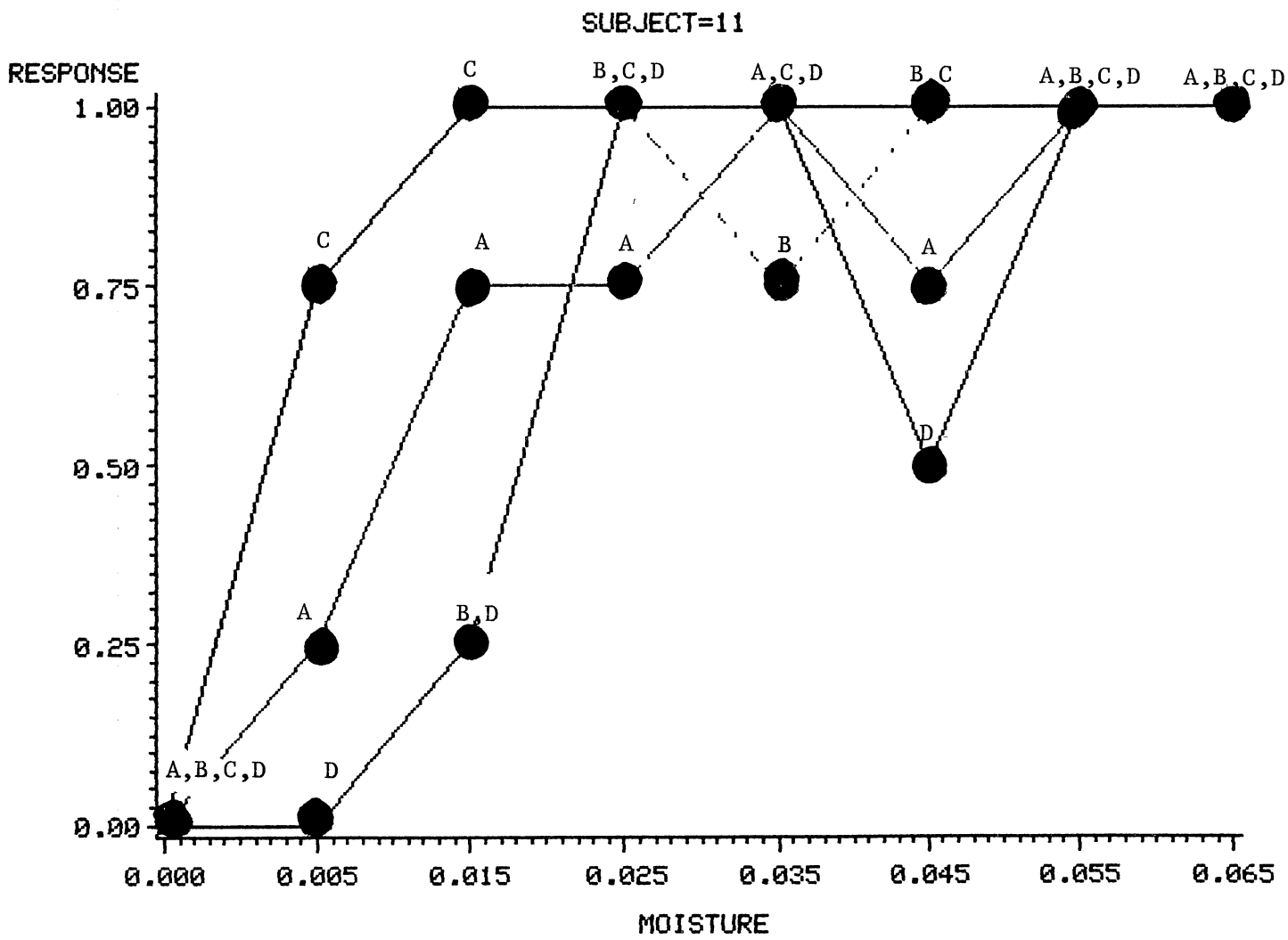

SUBJECT=6
RESPONSE
1.00
0.75
0.50
0.25
0.00
0.000
0.005
0.015
0.025
0.035
0.045
0.055
0.065
MOISTURE
A,B,C,D
A,B
B
C
C,D
D
A
A
D
C
C,D
D
C,D
A,B,C
B,D
A,B
A,B
A
C
B

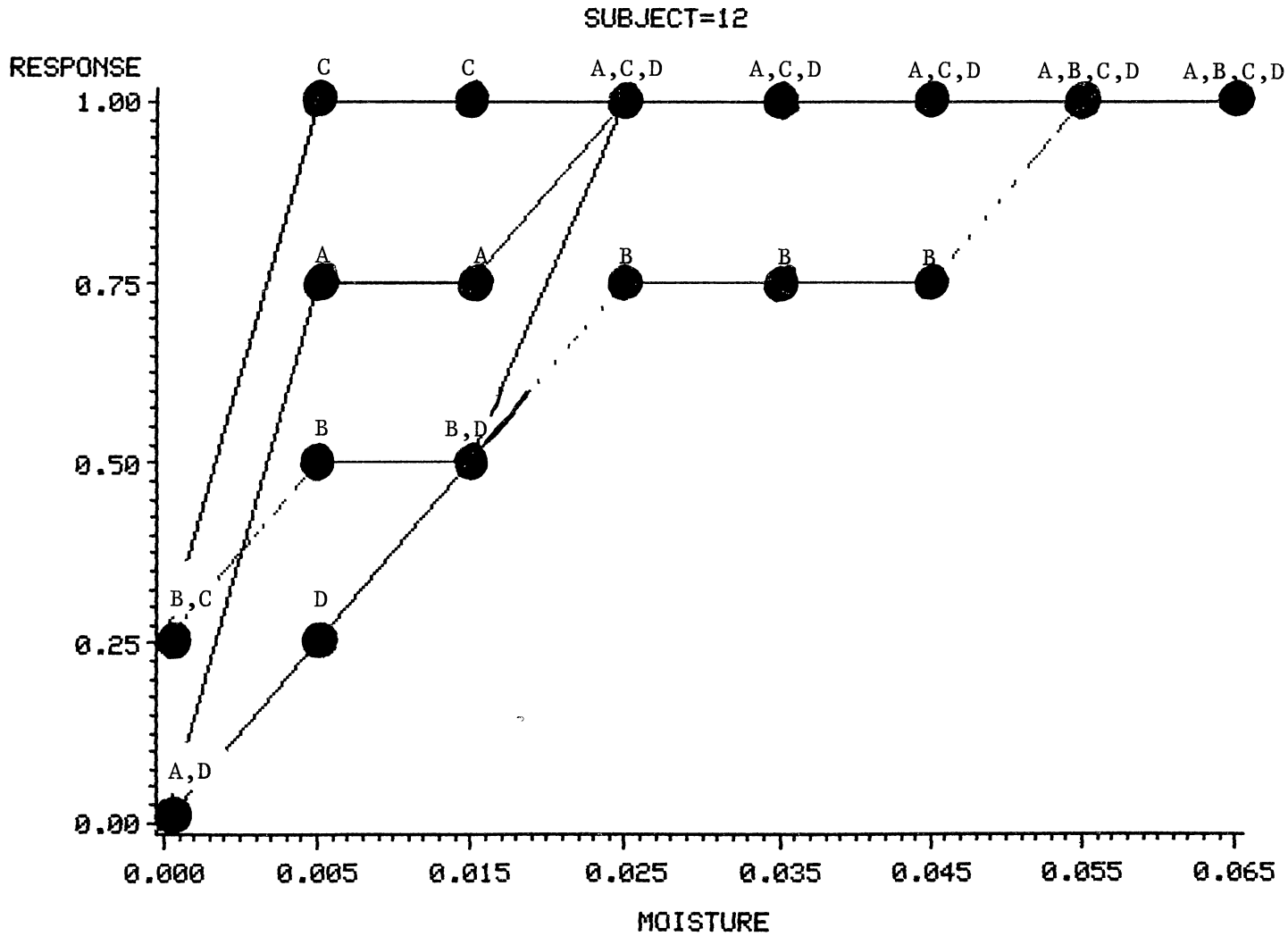

SUBJECT=7
RESPONSE
1.00
0.75
0.50
0.25
0.00
C
C
A,C,D
A,C,D
A,B,C
A,B,C,D
A,B,C,D
A
B
D
B
B
C
D
B,D
A,B,D
A
0.000
0.005
0.015
0.025
0.035
0.045
0.055
0.065
MOISTURE

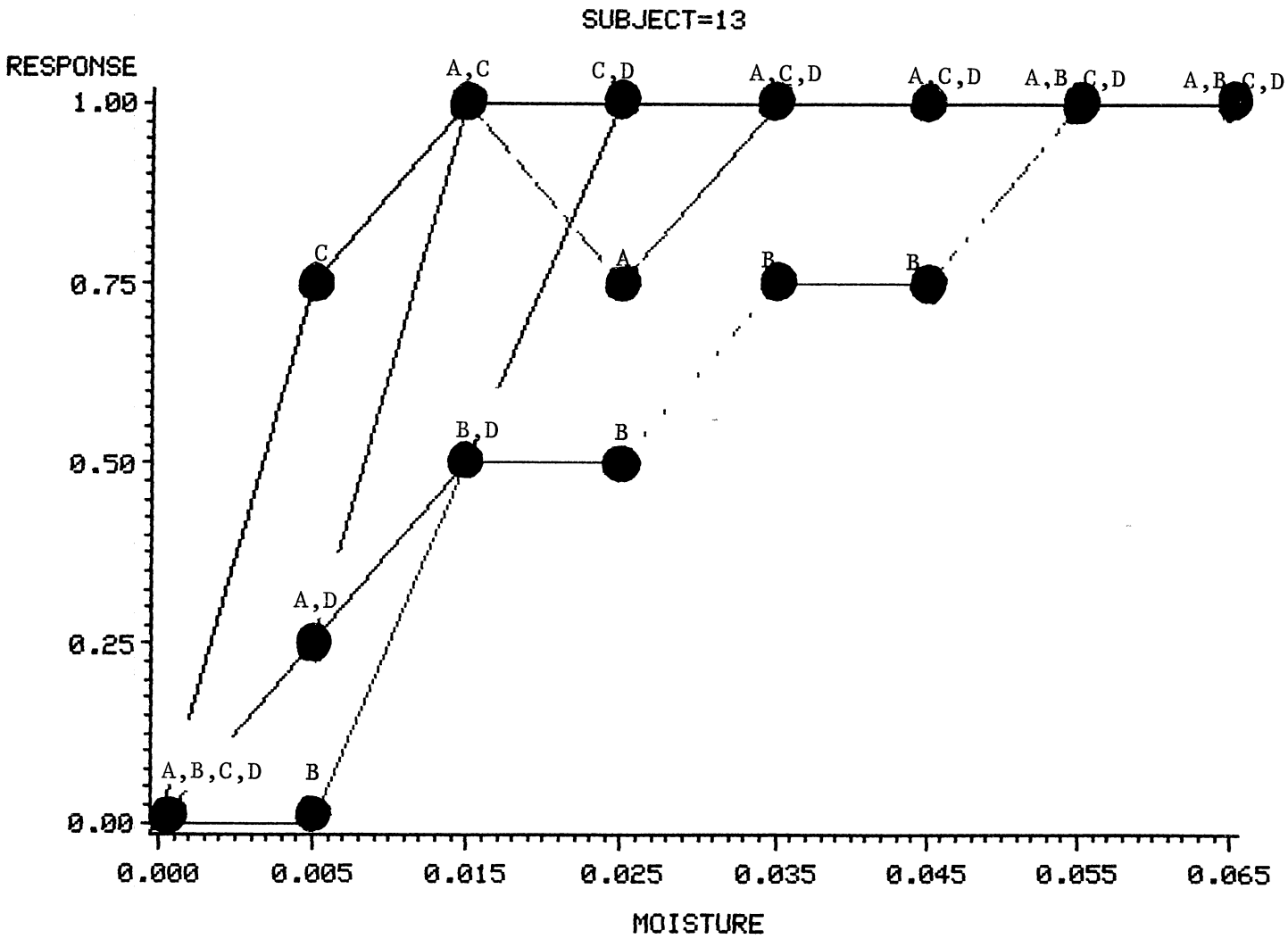

SUBJECT=8
RESPONSE
1.00
0.75
0.50
0.25
0.00
C
C
C,D
A,C
A,C
A,B,C,D
C
A,D
A
D
D
A,B,D
B
D
B
B
A,B,C,D
A,B
B
0.000
0.005
0.015
0.025
0.035
0.045
0.055
0.065
MOISTURE

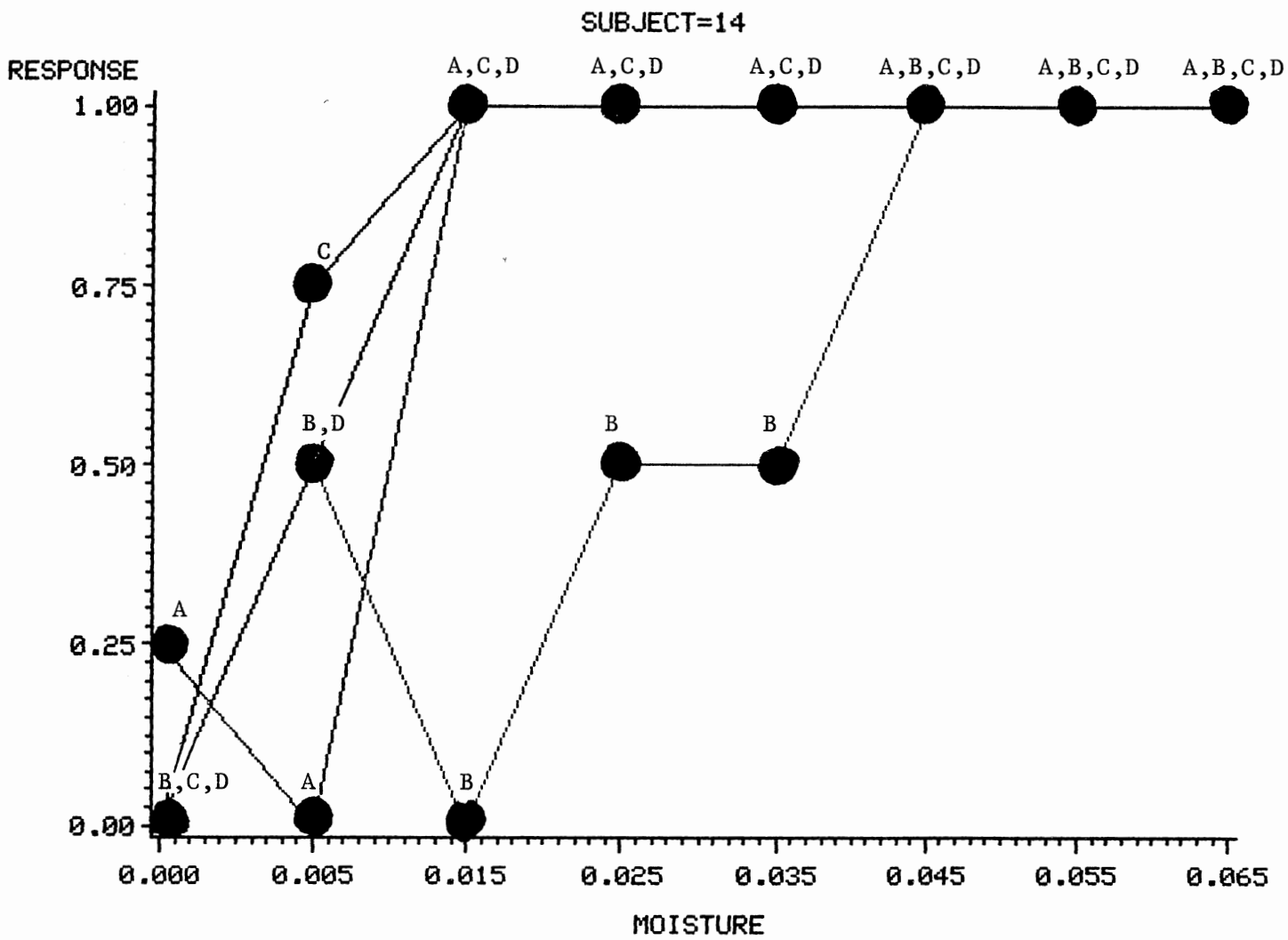

SUBJECT=9
RESPONSE
1.00
0.75
0.50
0.25
0.00
C
C,D
C,D
A,C,D
A,C,D
A,B,C,D
C
A
A
B
A,D
B
B
B
A,B,C,D
A,D
B
B
0.000
0.005
0.015
0.025
0.035
0.045
0.055
0.065
MOISTURE

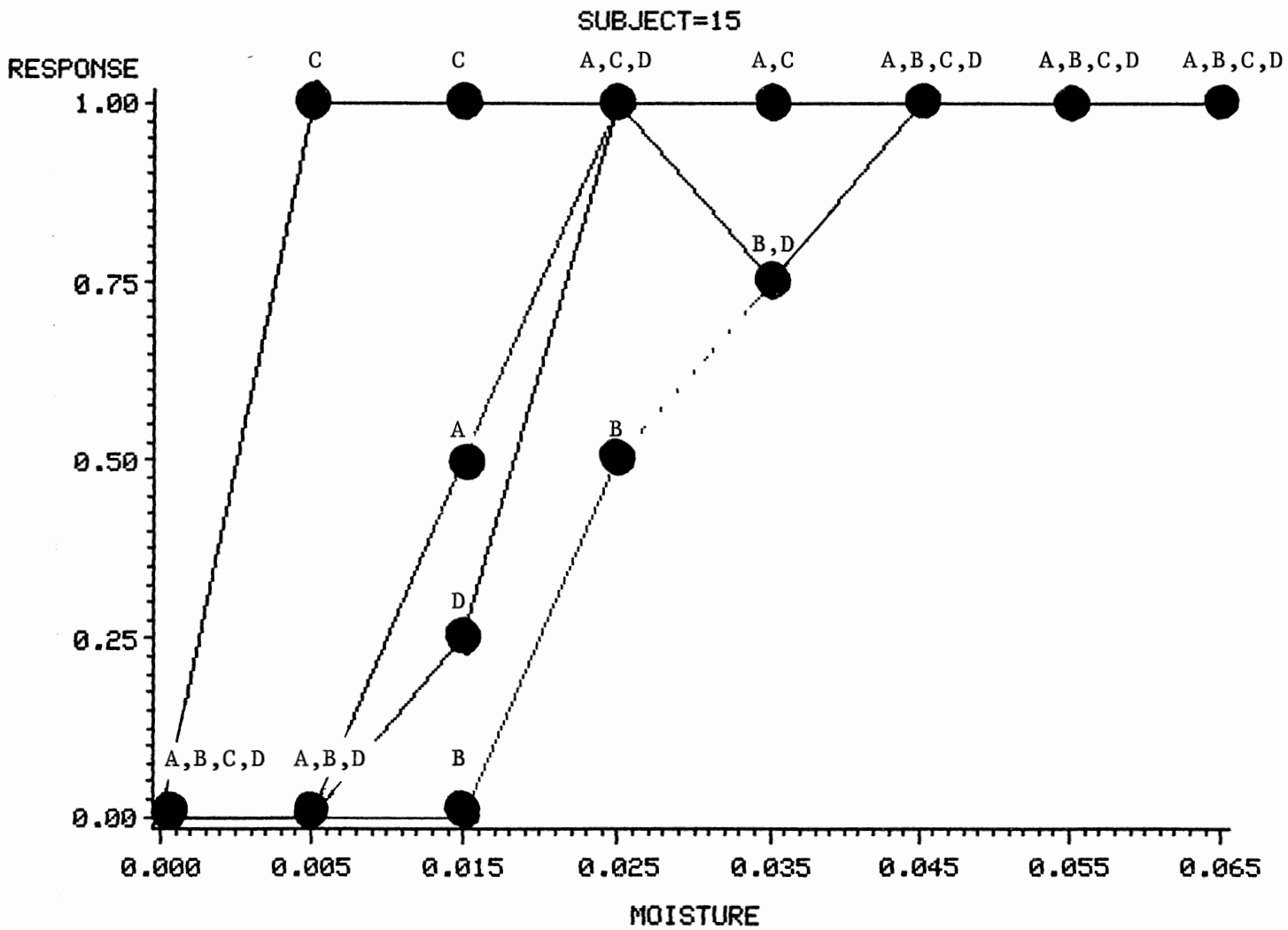

SUBJECT=10
RESPONSE
1.00
0.75
0.50
0.25
0.00
C
C
C
A,B,C,D
A,B,C,D
A,B,C,D
A,B,C,D
A
A,D
B
D
B
B
A,B,C
A
B,D
0.000
0.005
0.015
0.025
0.035
0.045
0.055
0.065
MOISTURE


SUBJECT=11
RESPONSE
1.00
0.75
0.50
0.25
0.00
C
B,C,D
A,C,D
B,C
A,B,C,D
A,B,C,D
C
A
A
B
A
D
A
B,D
A,B,C,D
D
0.000
0.005
0.015
0.025
0.035
0.045
0.055
0.065
MOISTURE


SUBJECT=12
RESPONSE
1.00
0.75
0.50
0.25
0.00
C
C
A,C,D
A,C,D
A,C,D
A,B,C,D
A,B,C,D
A
A
B
B
B
B
B,D
B,C
D
A,D
0.000
0.005
0.015
0.025
0.035
0.045
0.055
0.065
MOISTURE

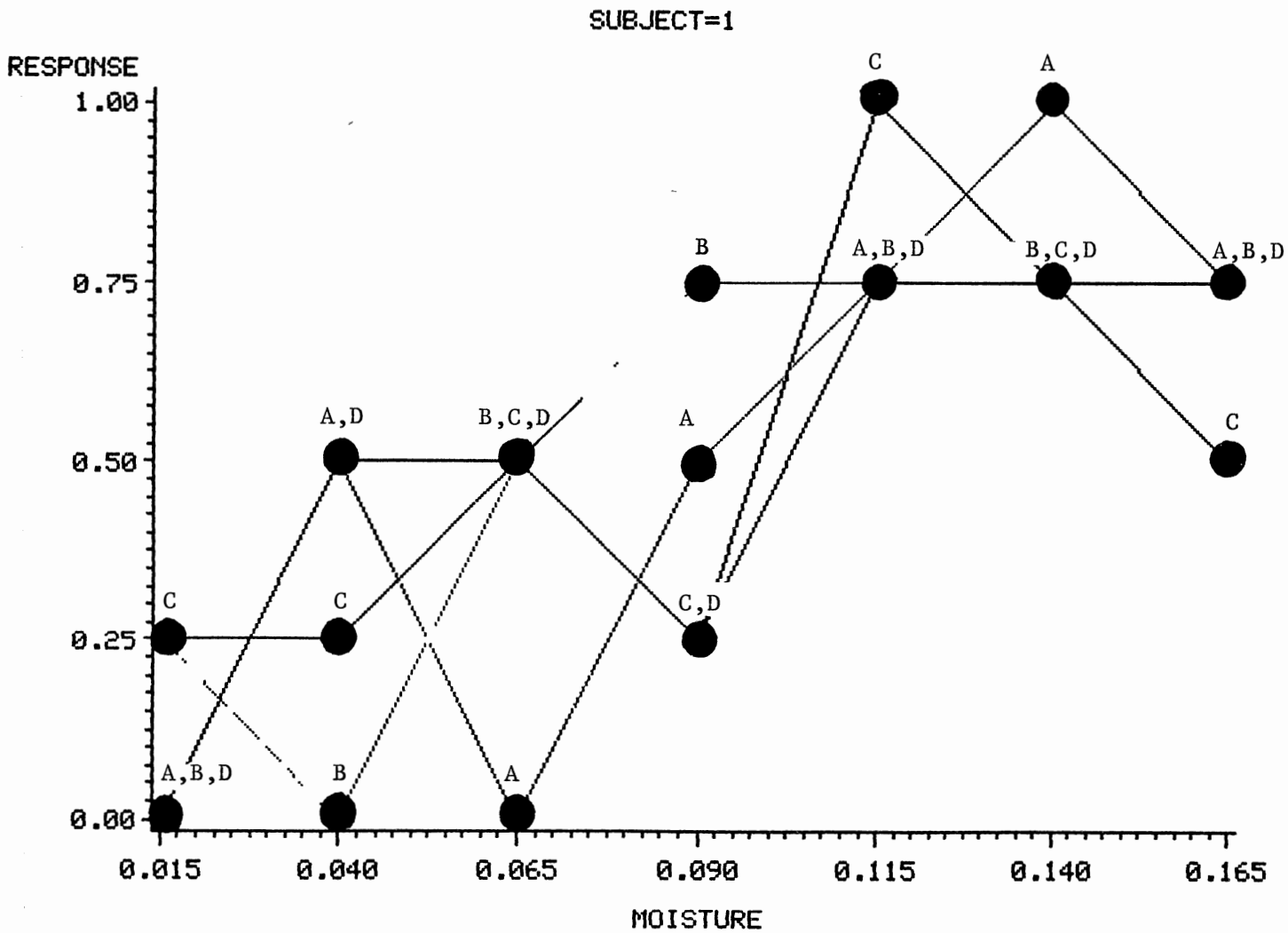

SUBJECT=13
RESPONSE
1.00
0.75
0.50
0.25
0.00
A,C
C,D
A,C,D
A,C,D
A,B,C,D
A,B,C,D
C
A
B
B
B,D
B
A,D
A,B,C,D
B
0.000
0.005
0.015
0.025
0.035
0.045
0.055
0.065
MOISTURE

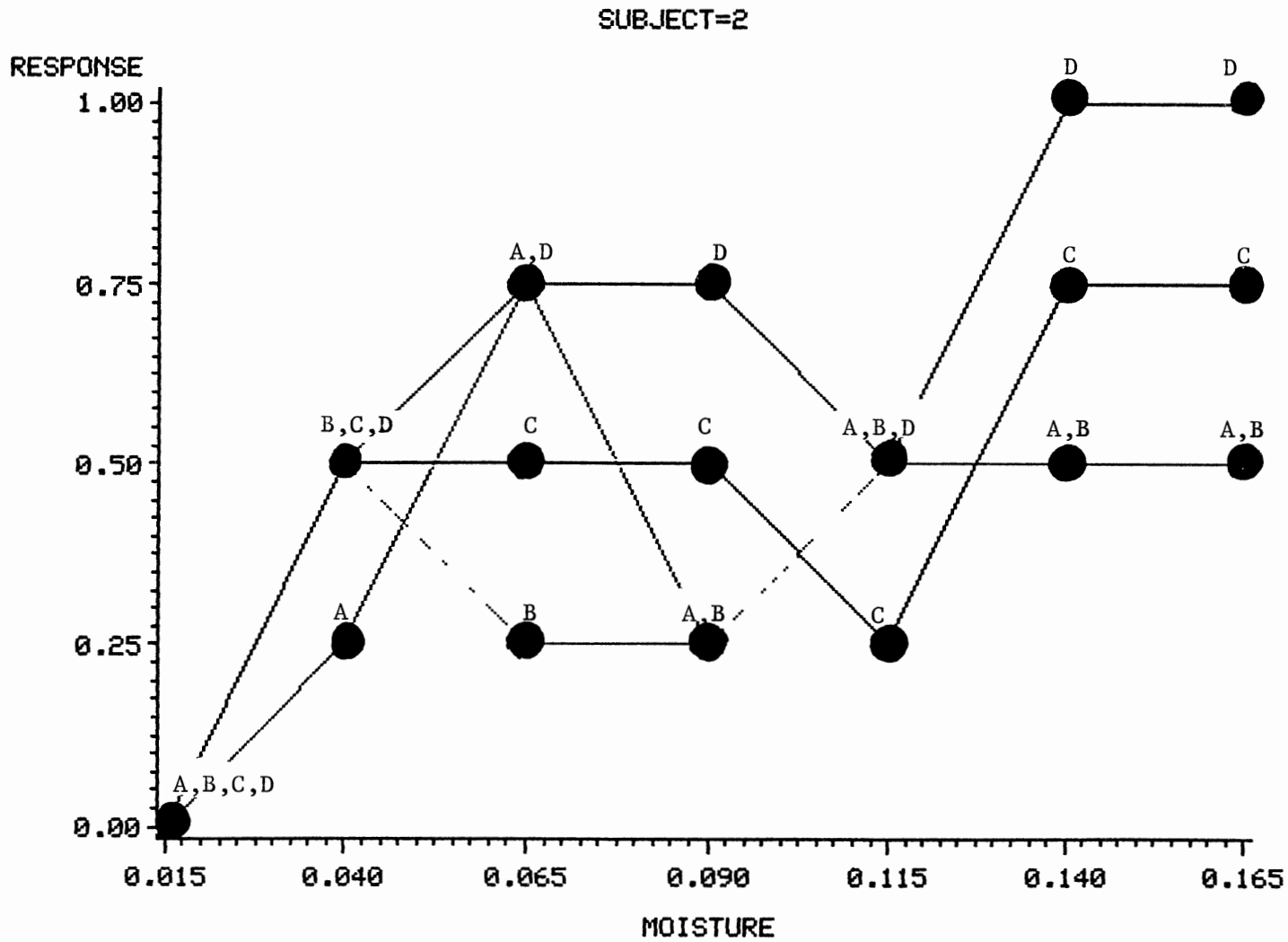

SUBJECT=14
RESPONSE
1.00
0.75
0.50
0.25
0.00
A,C,D
A,C,D
A,C,D
A,B,C,D
A,B,C,D
A,B,C,D
C
B,D
B
B
A
B,C,D
A
B
0.000
0.005
0.015
0.025
0.035
0.045
0.055
0.065
MOISTURE

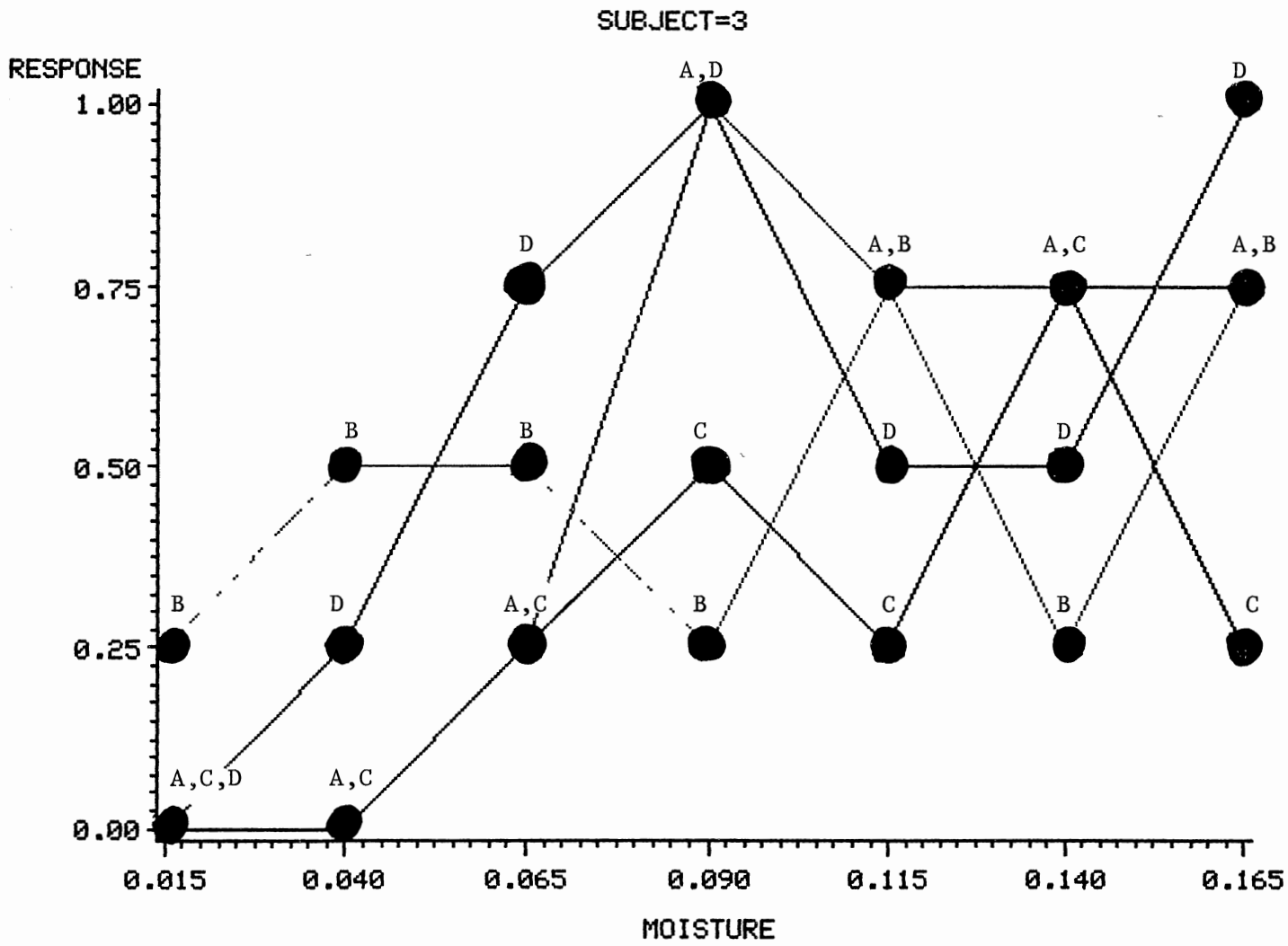

SUBJECT=15
RESPONSE
1.00
0.75
0.50
0.25
0.00
C
C
A,C,D
A,C
A,B,C,D
A,B,C,D
A,B,C,D
B,D
A
B
D
A,B,C,D
A,B,D
B
0.000
0.005
0.015
0.025
0.035
0.045
0.055
0.065
MOISTURE

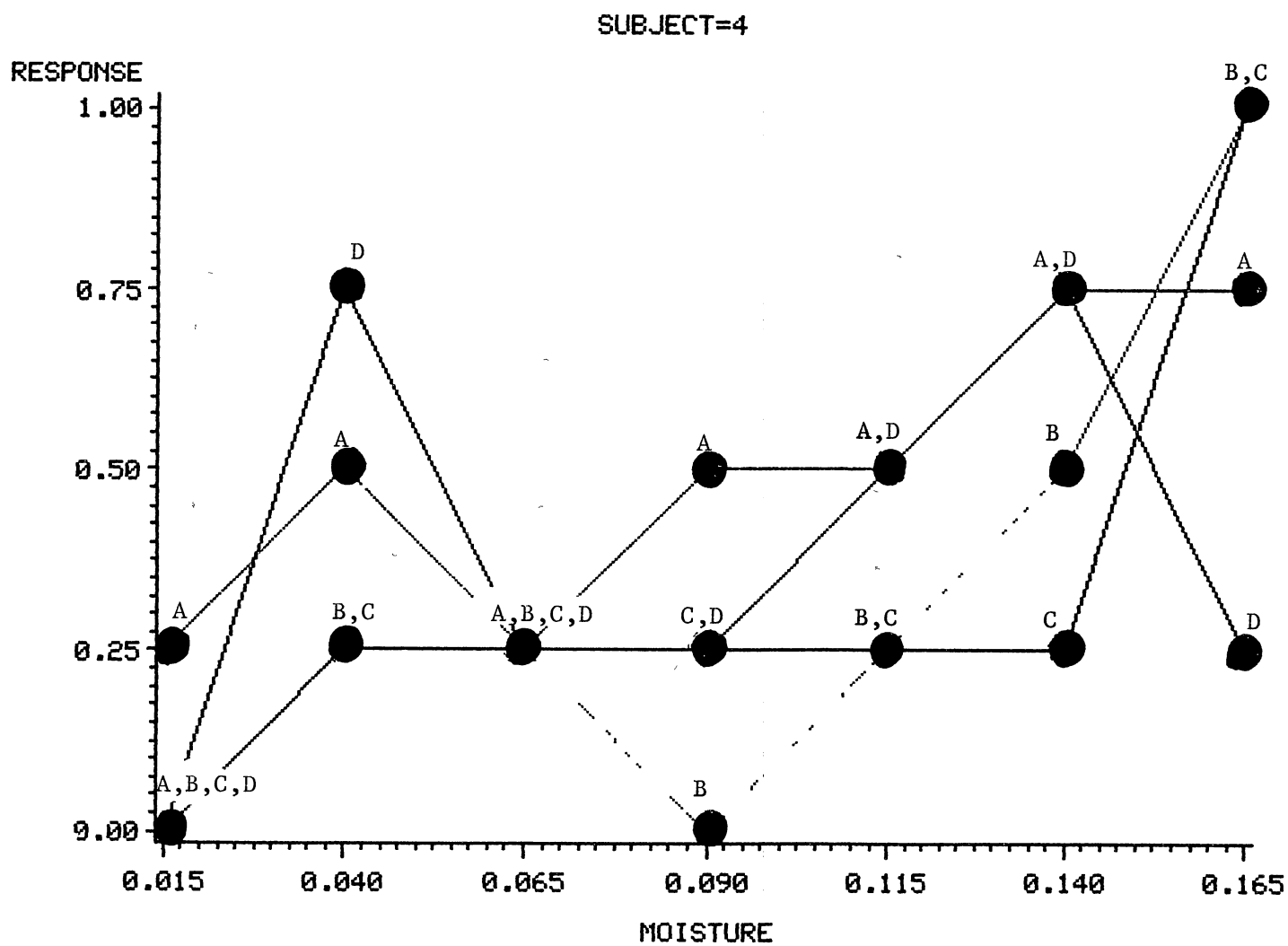
APPENDIX G

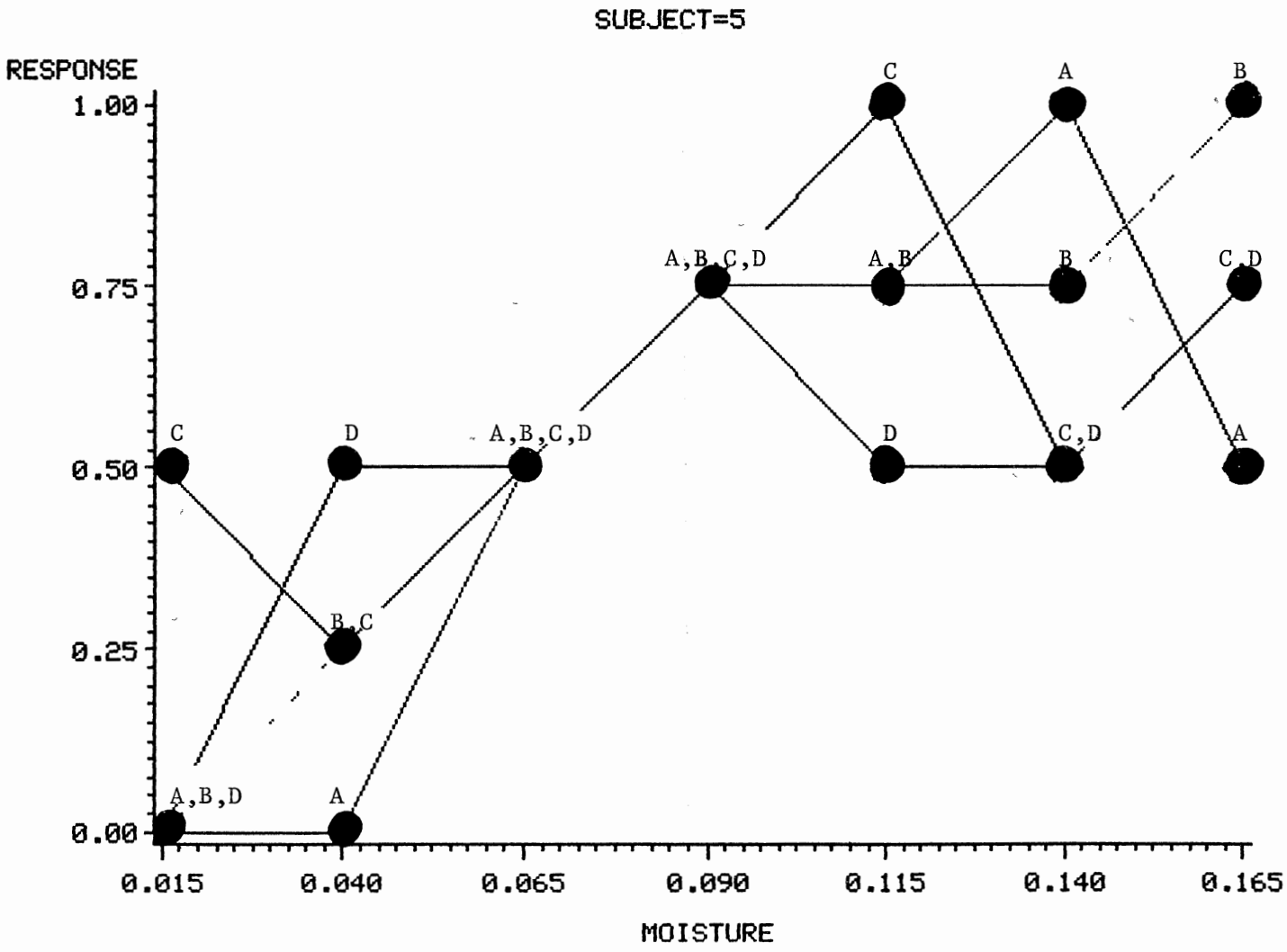
DL RAW DATA BY SUBJECT


SUBJECT=1
RESPONSE
1.00
0.75
0.50
0.25
0.00
0.015
0.040
0.065
0.090
0.115
0.140
0.165
MOISTURE
C
A,B,D
A,D
C
B
B,C,D
A
B
A
C,D
A,B,D
C
A
B,C,D
A,B,D
C


SUBJECT=2
RESPONSE
1.00
0.75
0.50
0.25
0.00
0.015
0.040
0.065
0.090
0.115
0.140
0.165
MOISTURE
A,B,C,D
B,C,D
A,D
D
A,B,D
D
D
A
B
A,B
C
C
C
C
A,B
A,B


SUBJECT=3
RESPONSE
1.00
0.75
0.50
0.25
0.00
0.015
0.040
0.065
0.090
0.115
0.140
0.165
MOISTURE
A,D
D
A,B
A,C
A,B
B
B
C
D
D
B
D
A,C
B
C
B
C
A,C,D
A,C


SUBJECT=4
RESPONSE
1.00
0.75
0.50
0.25
0.00
0.015
0.040
0.065
0.090
0.115
0.140
0.165
MOISTURE
A
D
A
B,C
A,B,C,D
A,B,C,D
A
C,D
A,D
B
B,C
A,D
B
C
B,C
A
D


SUBJECT=5
RESPONSE
1.00
0.75
0.50
0.25
0.00
0.015
0.040
0.065
0.090
0.115
0.140
0.165
MOISTURE
C
D
A,B,C,D
B,C
A,B,D
A
A,B,C,D
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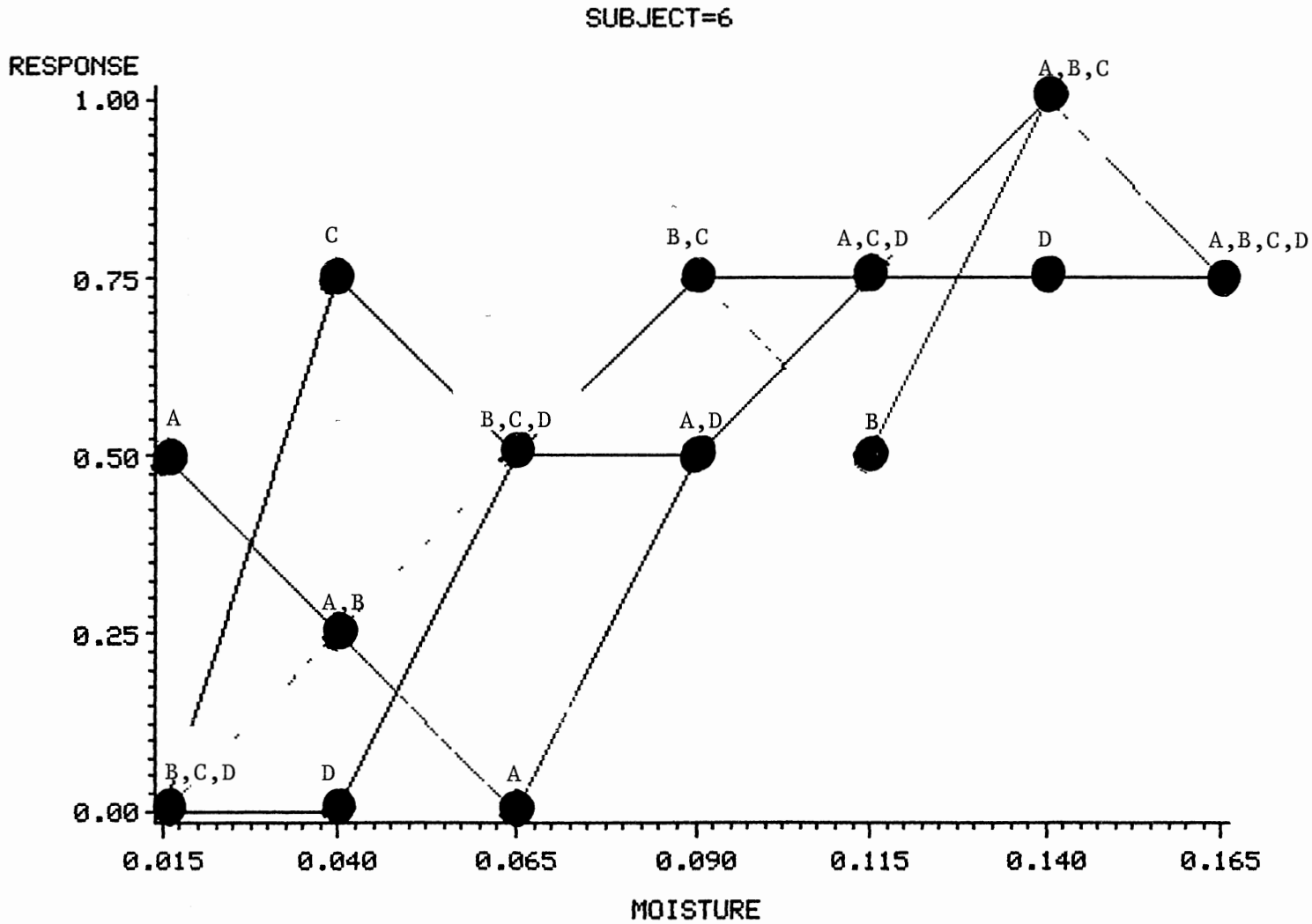
B
C,D
D
C,D
A
C
A
B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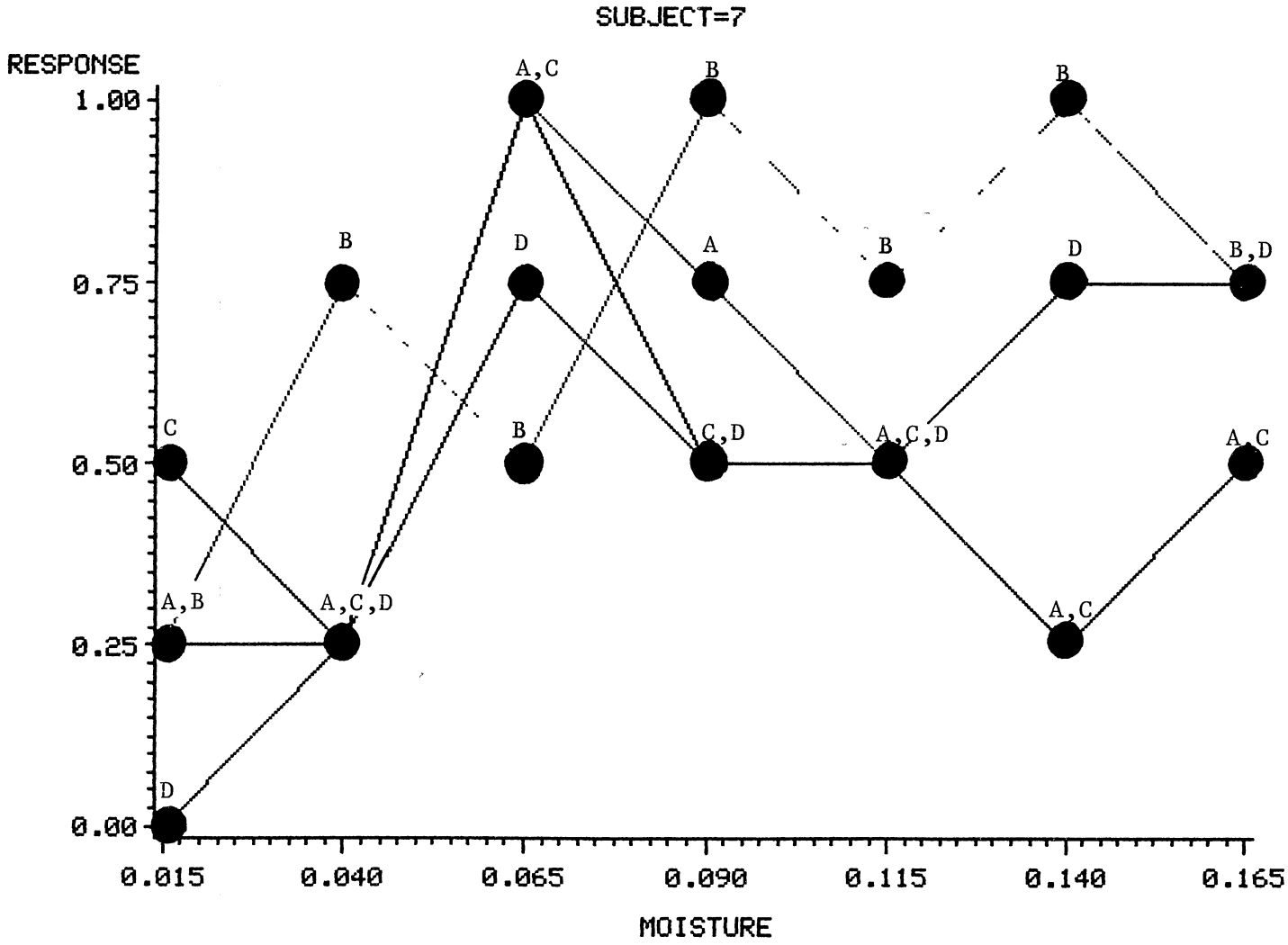
A,C,D
D
A,B,C,D
A
B,C,D
A,D
B
A,B
B,C,D
D
A
0.015
0.040
0.065
0.090
0.115
0.140
0.165
MOISTURE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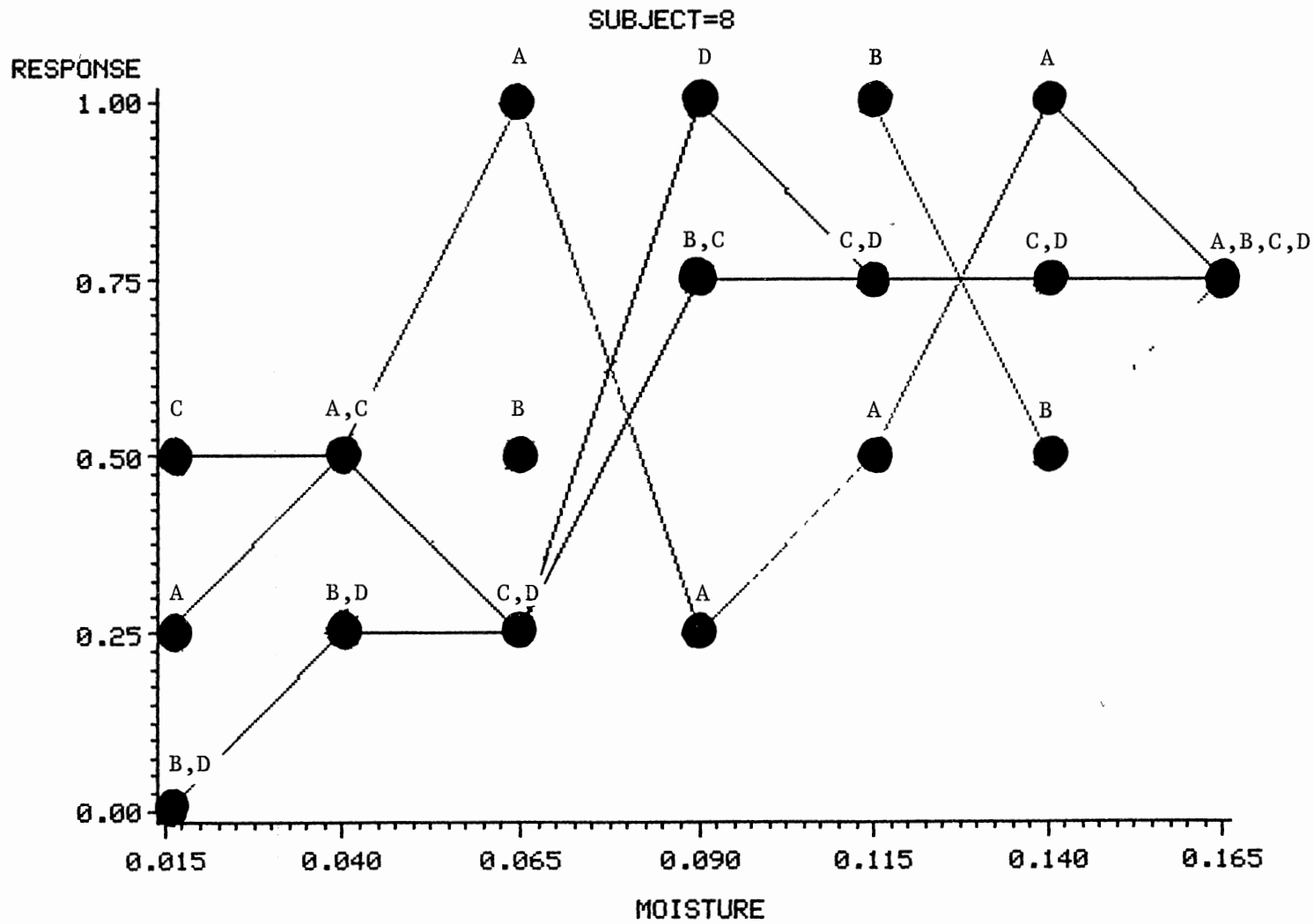
0.115
0.140
0.165
MOISTURE
C
A,B
D
B
A,C,D
A,C
D
B
B
C,D
A
B
A,C,D
B
D
A,C
B,D
A,C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0.015
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0.065
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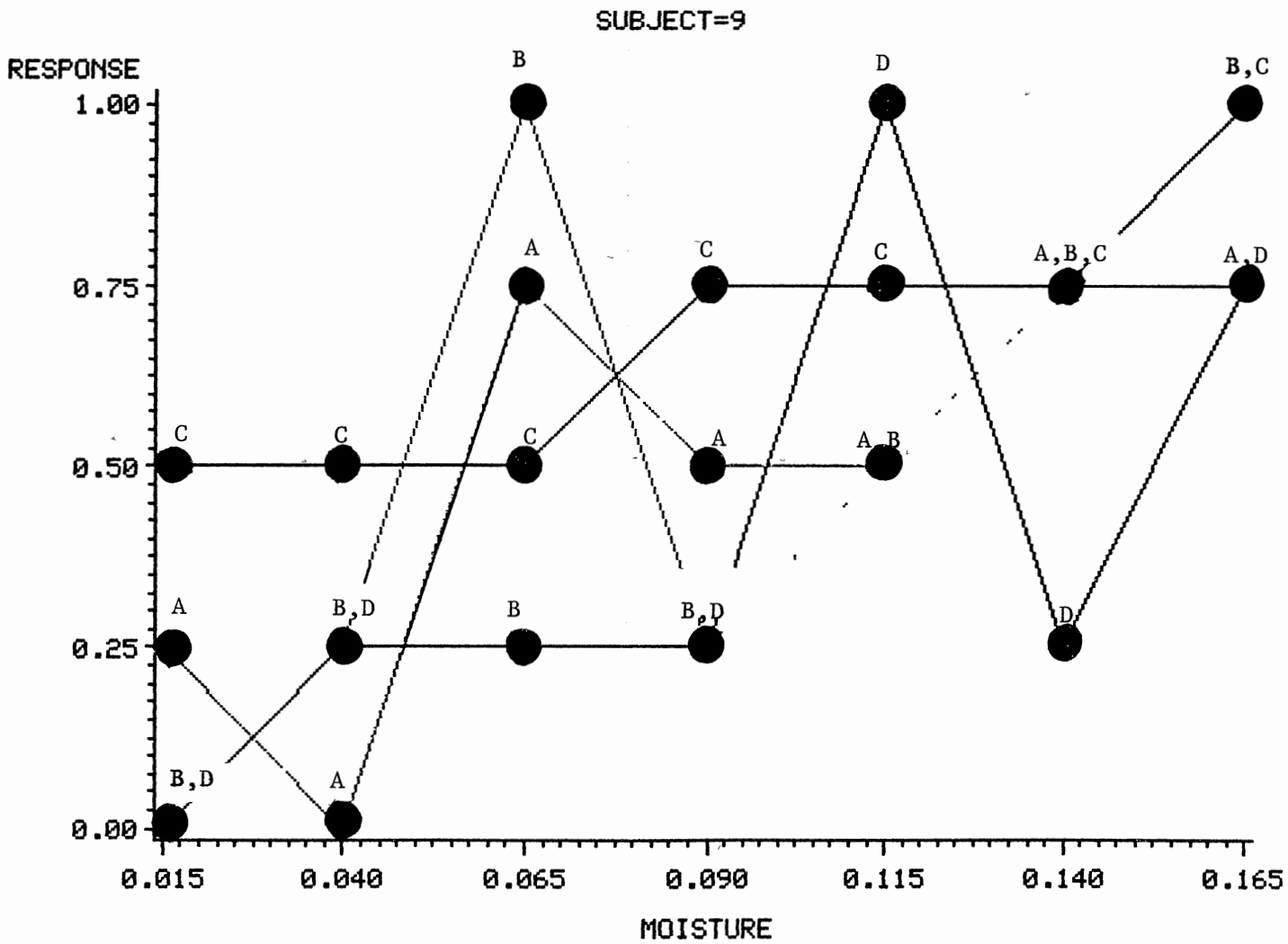
0.115
0.140
0.165
MOISTURE
A
D
B
A
B,C
C,D
C,D
A,B,C,D
C
A,C
B
A
B
A
B,D
C,D
A
B,D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0.065
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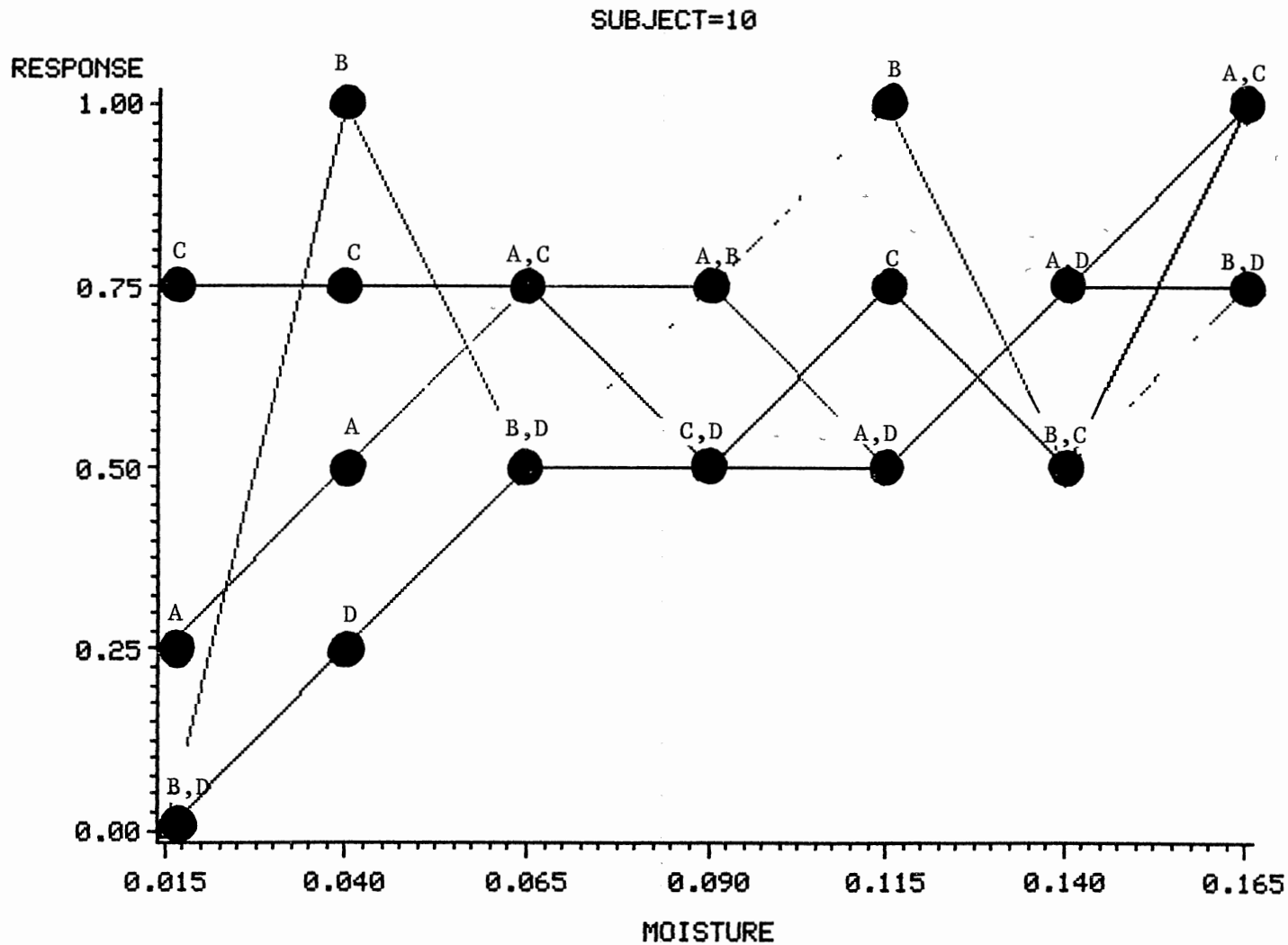
0.140
0.165
MOISTURE
B
D
B,C
A
C
C
A,B,C
A,D
C
C
C
A
A,B
A
B,D
B
B,D
D
B,D
A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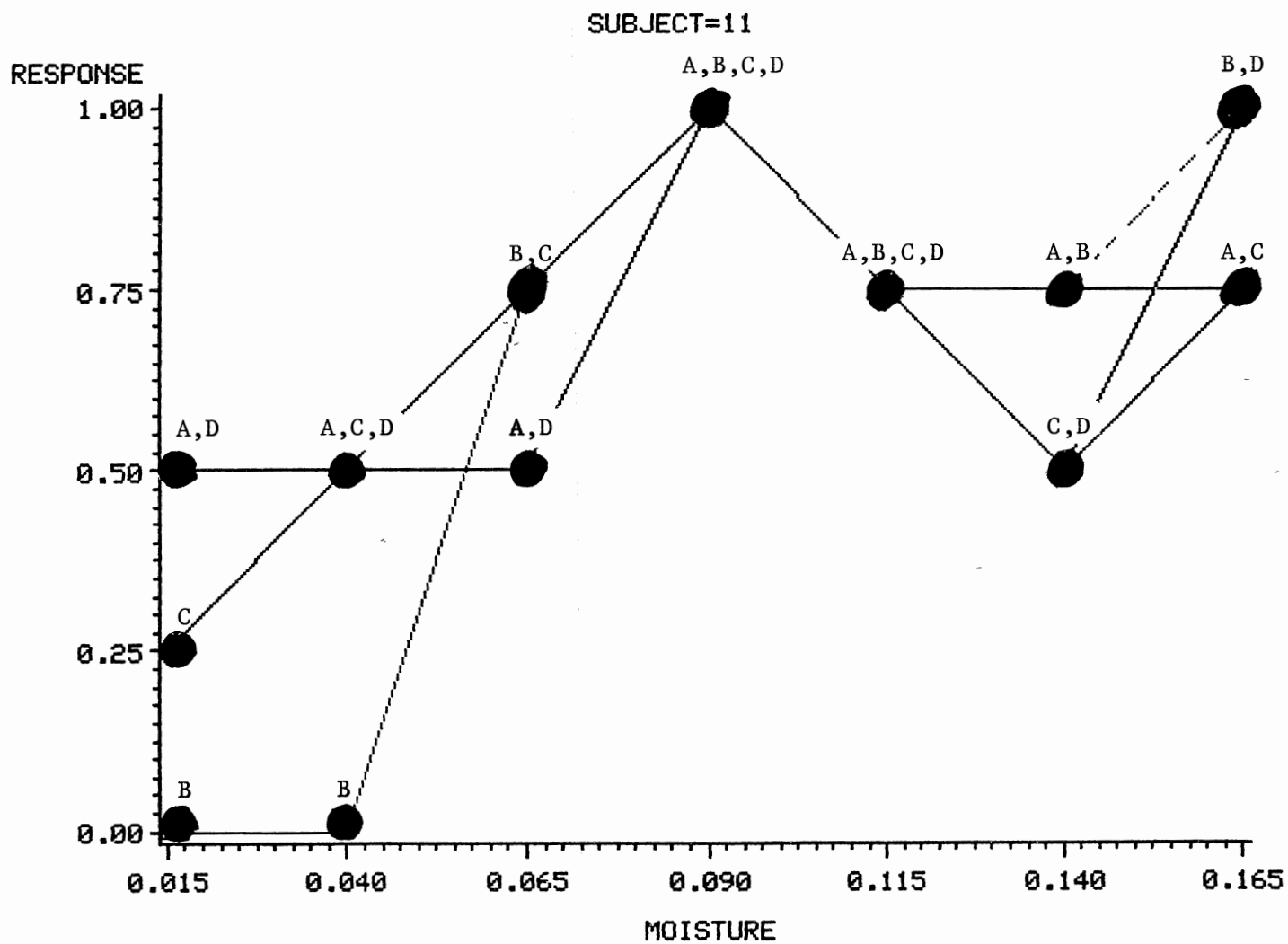
0.065
0.090
0.115
0.140
0.165
MOISTURE
C
C
A,C
A,B
C
A,D
B,D
A
B,D
C,D
A,D
B,C
A
D
B,D
B
B
A,C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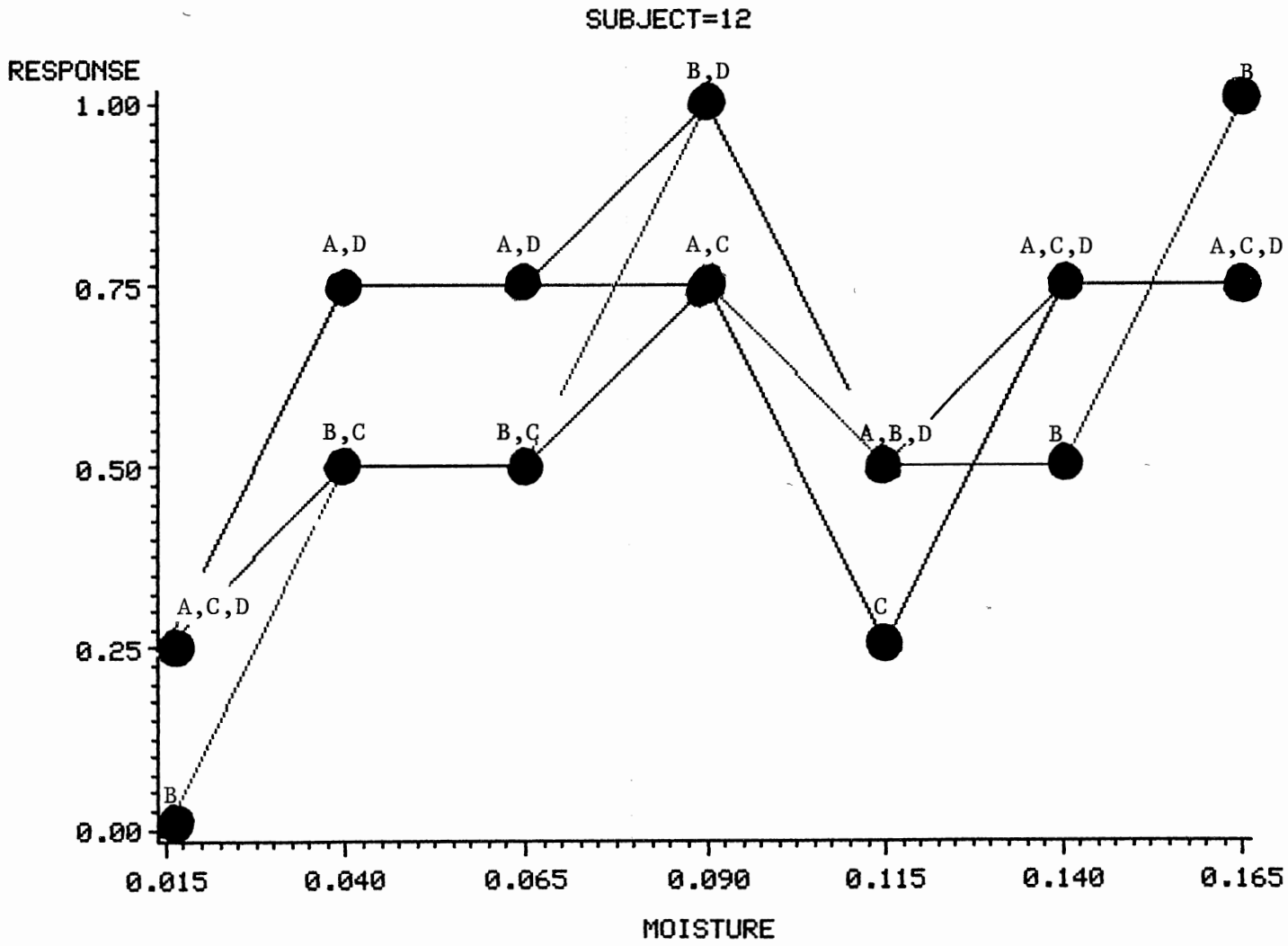
A,B,C,D
B,D
B,C
A,B,C,D
A,B
A,C
A,D
A,C,D
A,D
C,D
C
B
B
0.015
0.040
0.065
0.090
0.115
0.140
0.165
MOISTURE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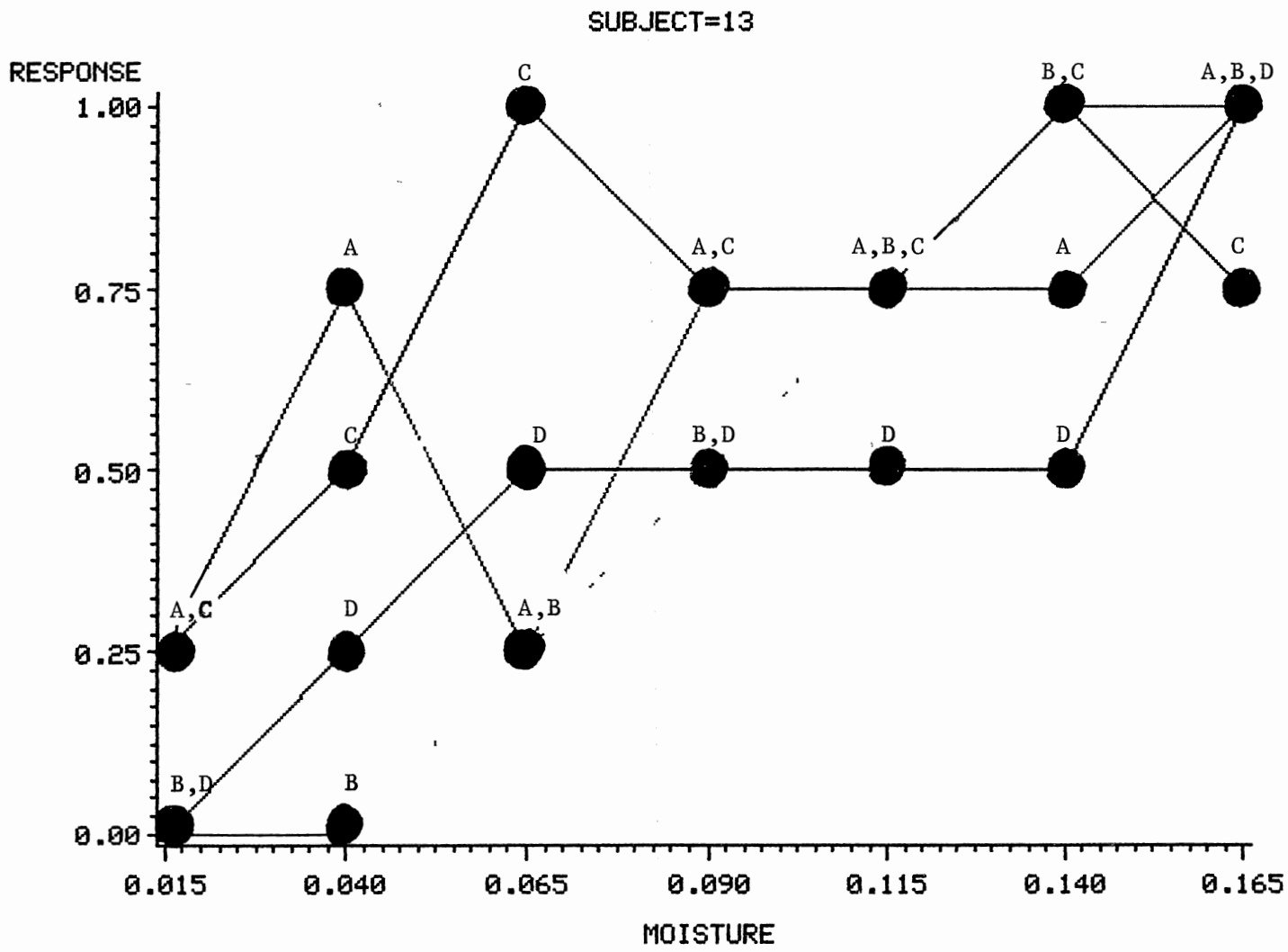
A,C
A,C,D
A,C,D
B,D
B
B,C
B,C
A,B,D
B
A,C,D
C
B
0.015
0.040
0.065
0.090
0.115
0.140
0.165
MOISTURE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0.25
0.00
0.015
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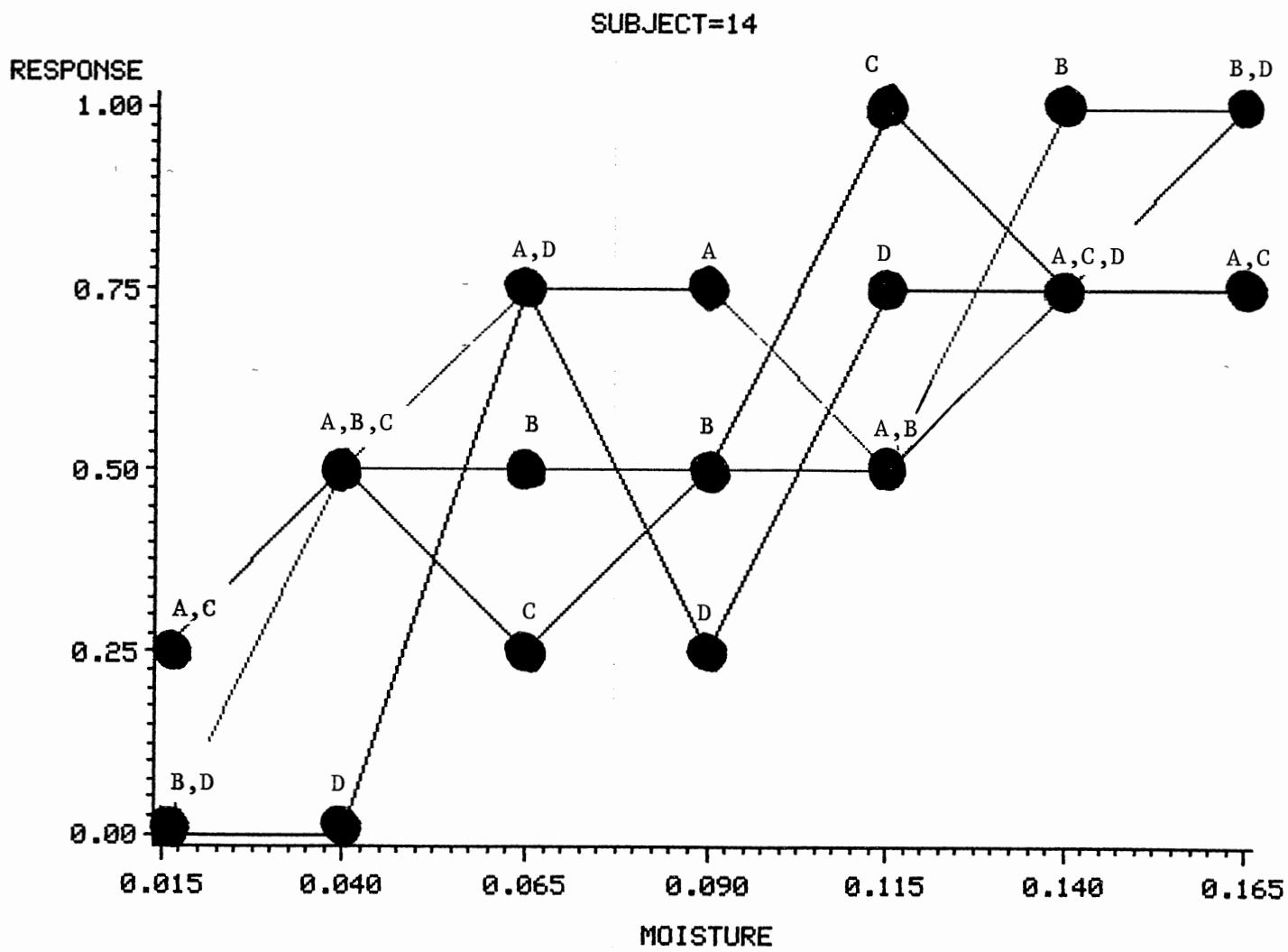
0.065
0.090
0.115
0.140
0.165
MOISTURE
A,C
B,D
A
C
B
C
D
A,B
A,C
B,D
A,B,C
D
B,C
A
D
A,B,D
C
D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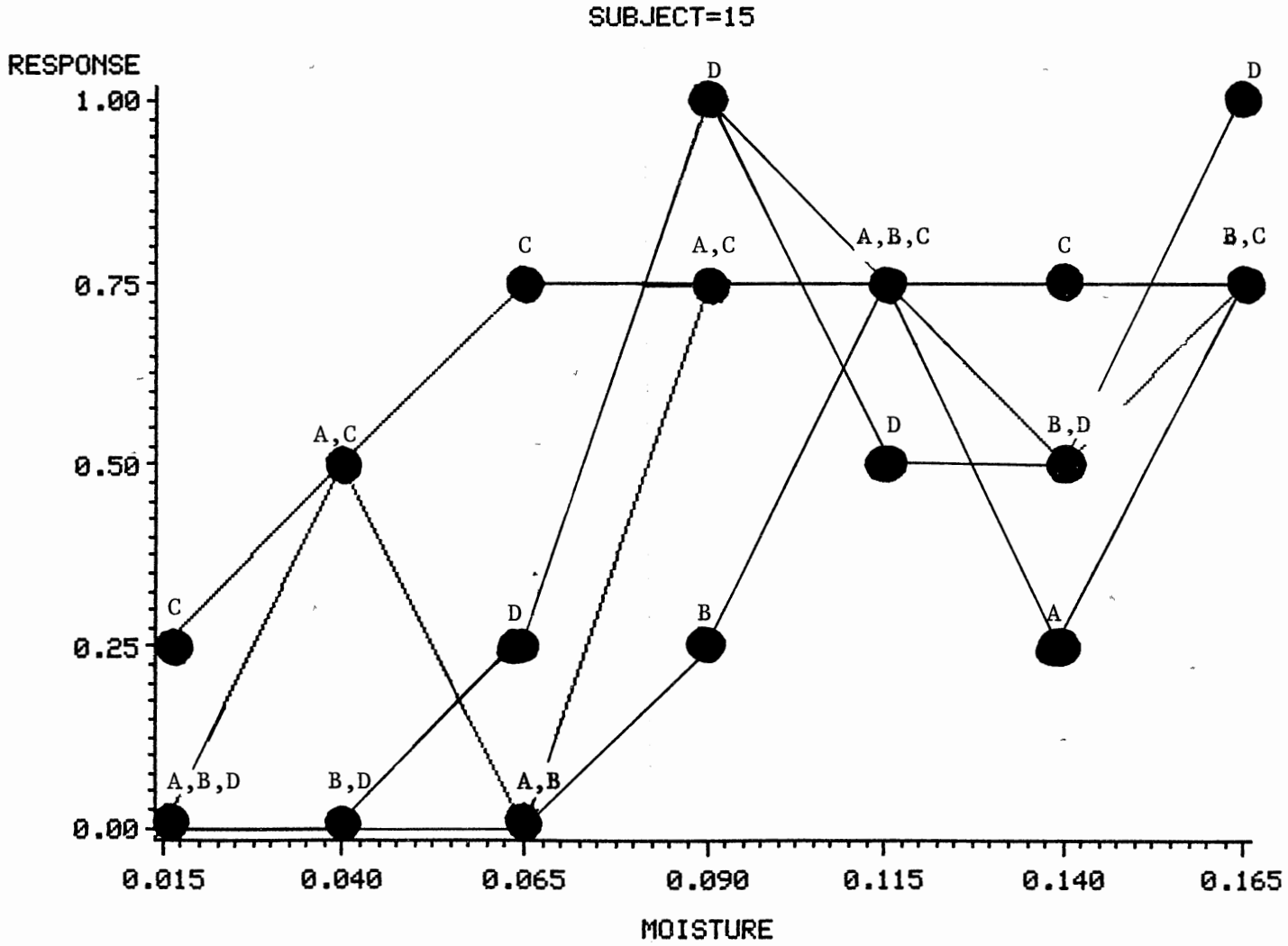
0.50
0.25
0.00
0.015
0.040
0.065
0.090
0.115
0.140
0.165
MOISTURE
A,C
A,B,C
A,D
A
D
A,C,D
A,C
B,D
D
B
B
A,B
C
D
C
B
B,D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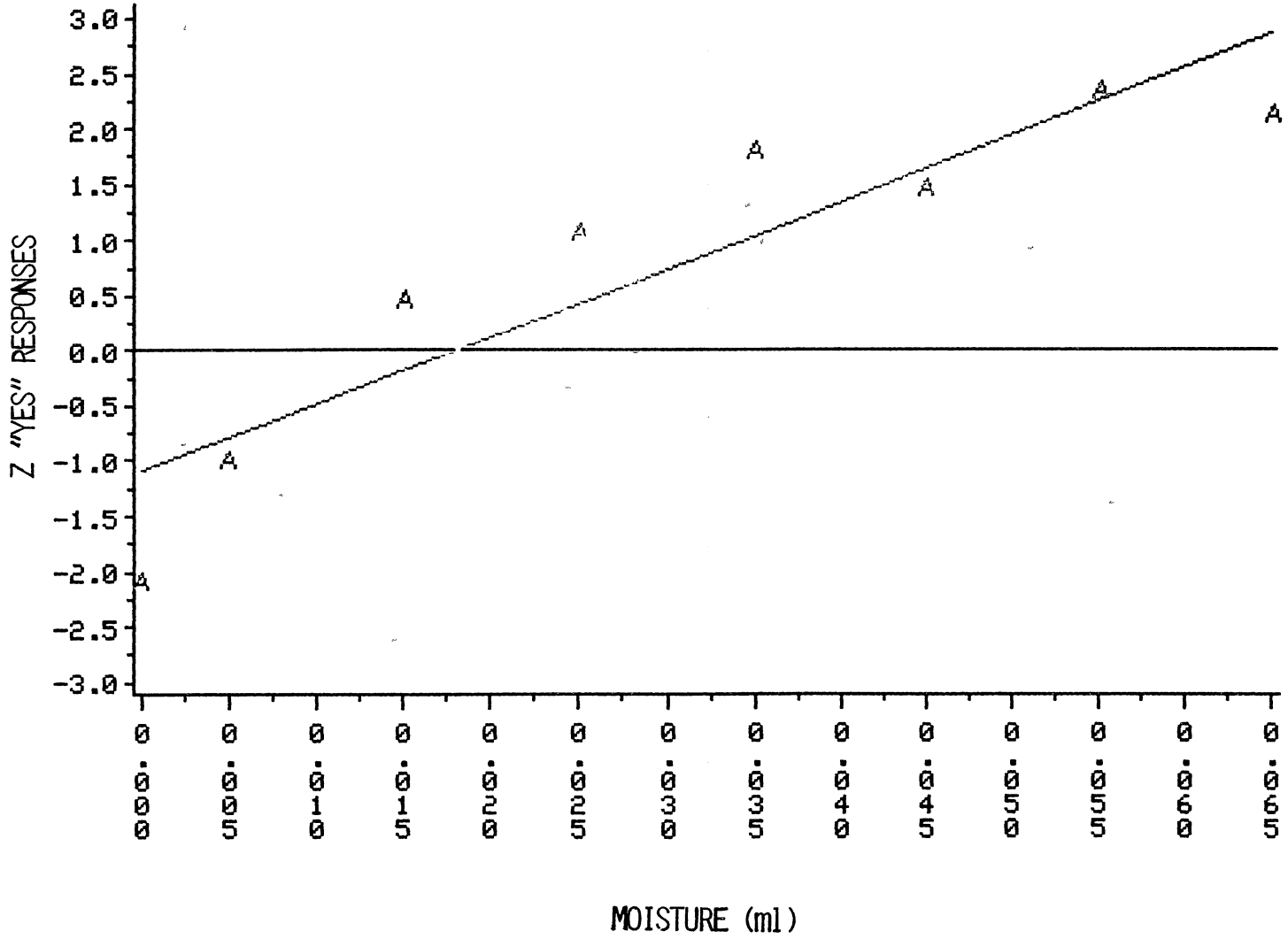
0.25
0.00
0.015
0.040
0.065
0.090
0.115
0.140
0.165
MOISTURE
C
A,C
C
D
A,C
A,B,C
C
B,C
D
D
B,D
A
B
A,B,D
B,D
A,B

APPENDIX H

FIT OF DATA POINTS TO AL REGRESSION LINES


Z "YES" RESPONSES
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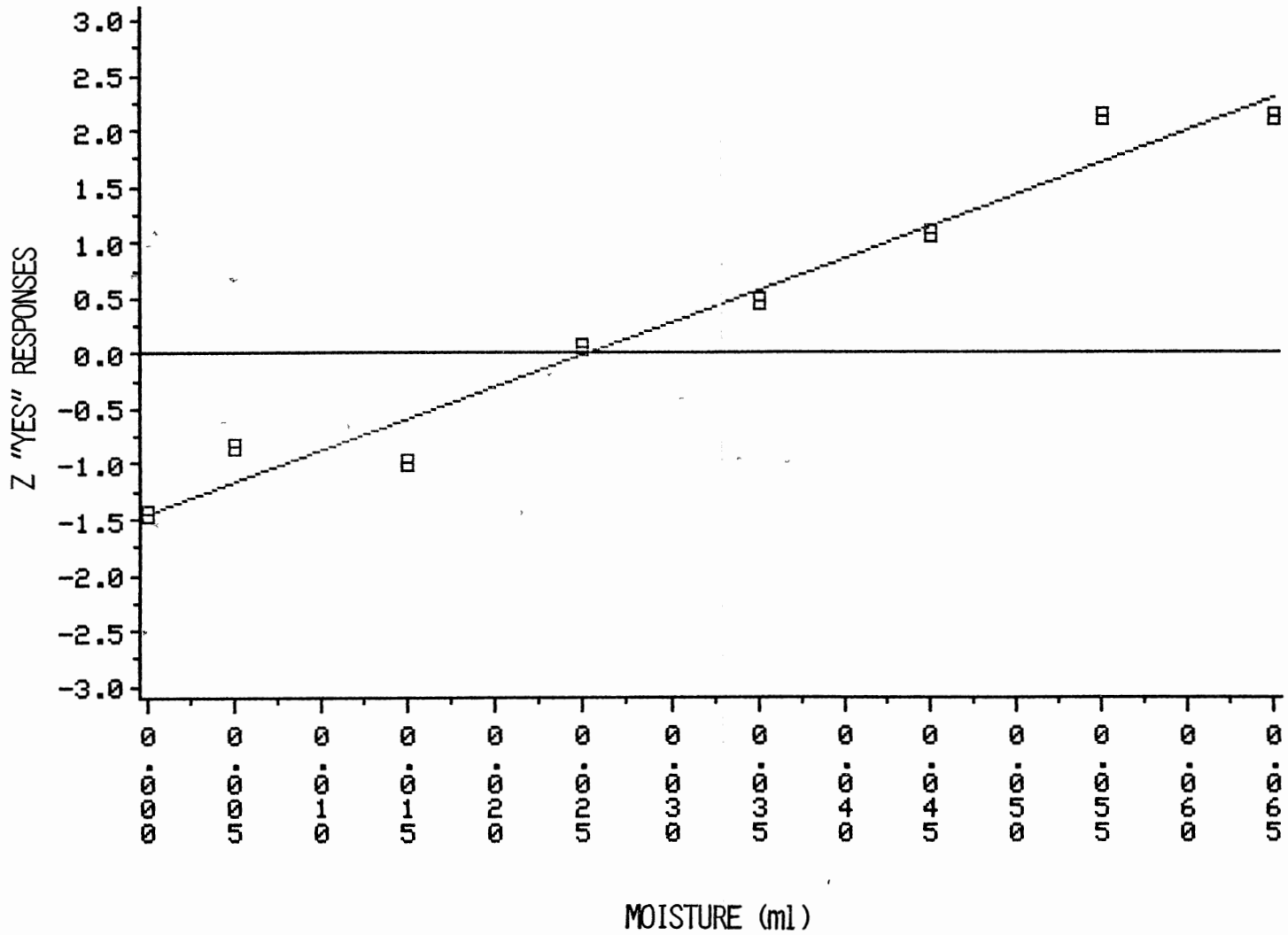
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
0.000
0.005
0.010
0.015
0.020
0.025
0.030
0.035
0.040
0.045
0.050
0.055
0.060
0.065
MOISTURE (ml)


Z "YES" RESPONSES
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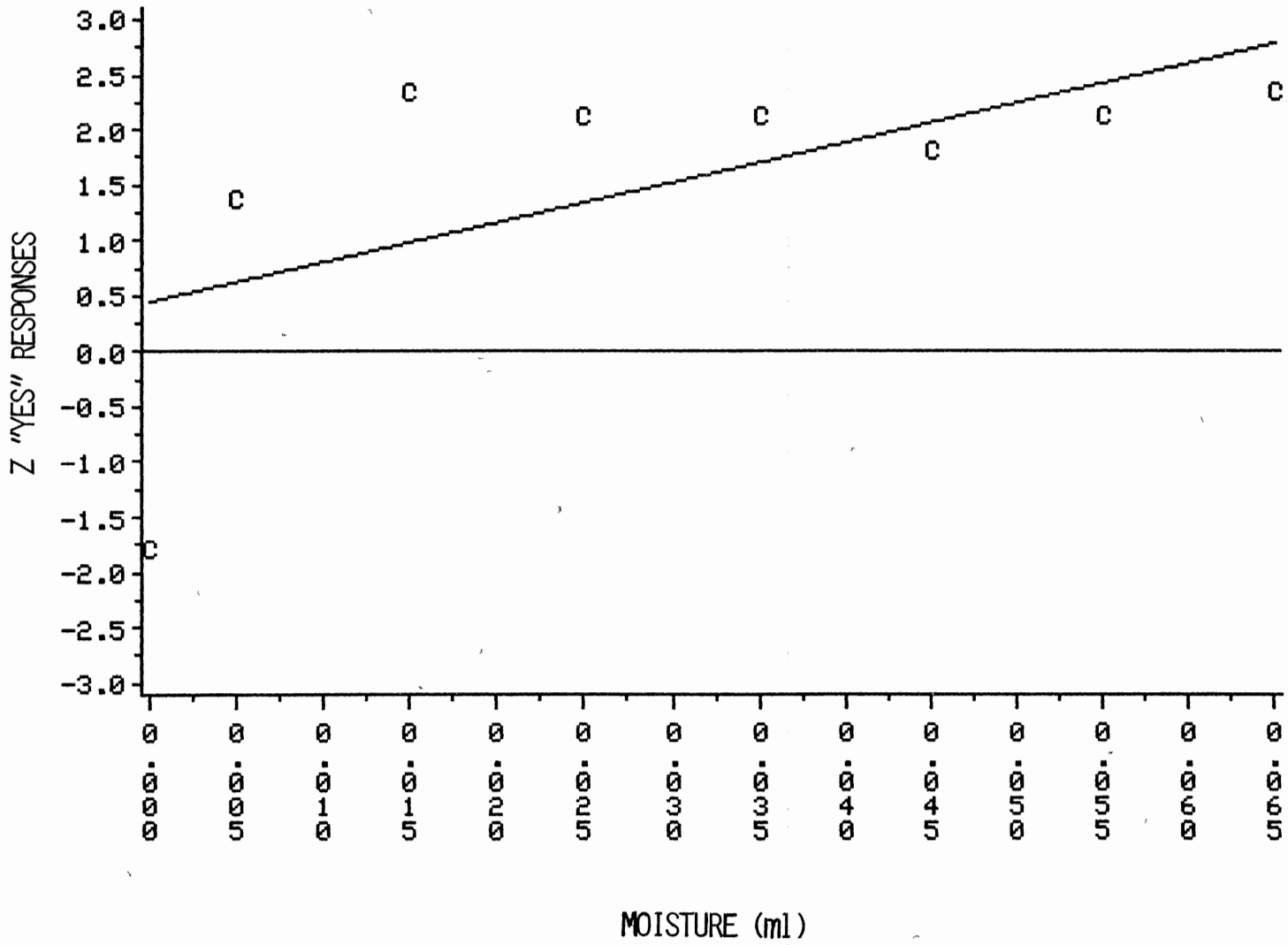
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
0.000
0.005
0.010
0.015
0.020
0.025
0.030
0.035
0.040
0.045
0.050
0.055
0.060
0.065
MOISTURE (ml)


Z "YES" RESPONSES
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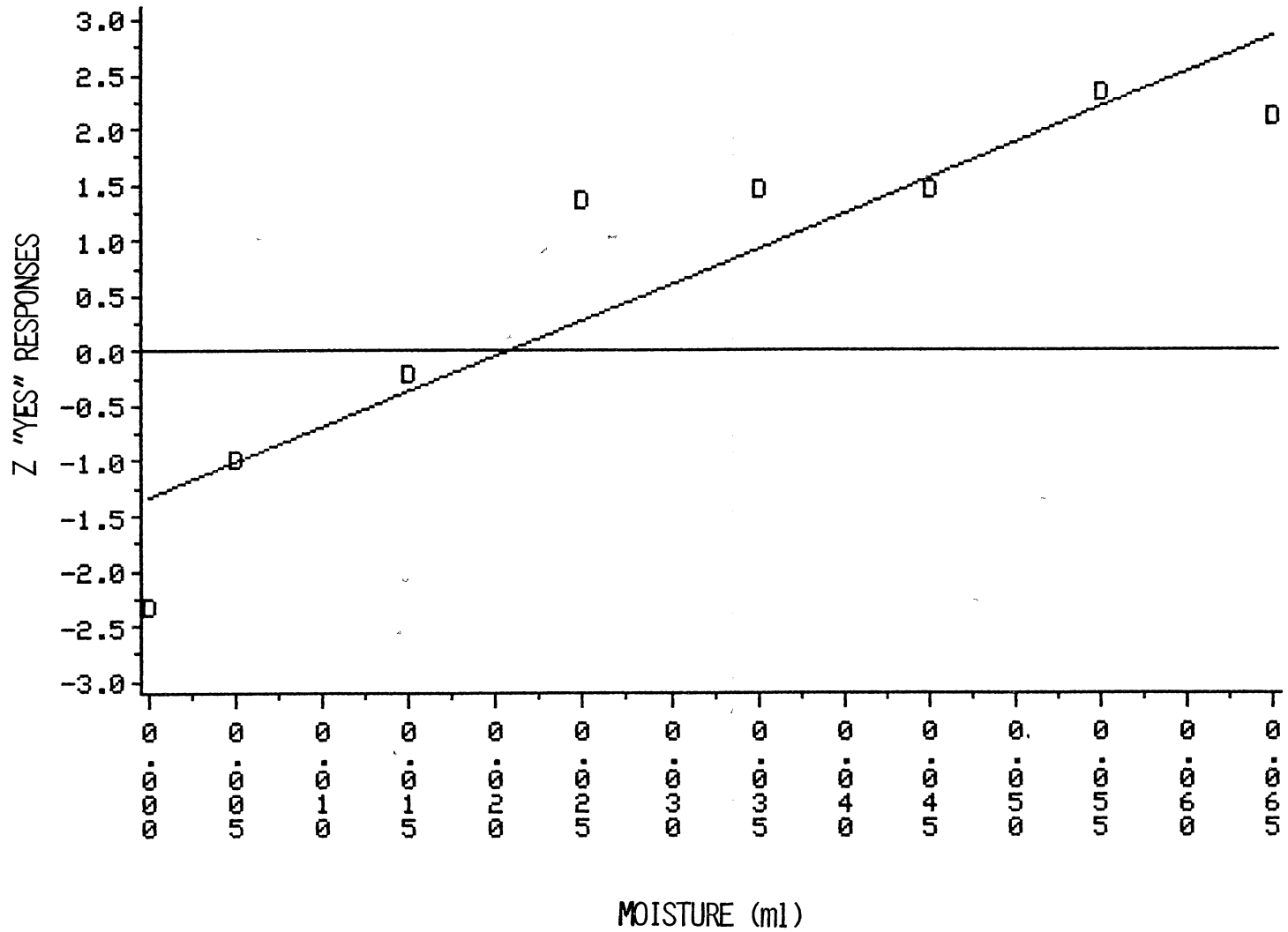
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
0.000
0.005
0.010
0.015
0.020
0.025
0.030
0.035
0.040
0.045
0.050
0.055
0.060
0.065
MOISTURE (ml)


Z "YES" RESPONSES
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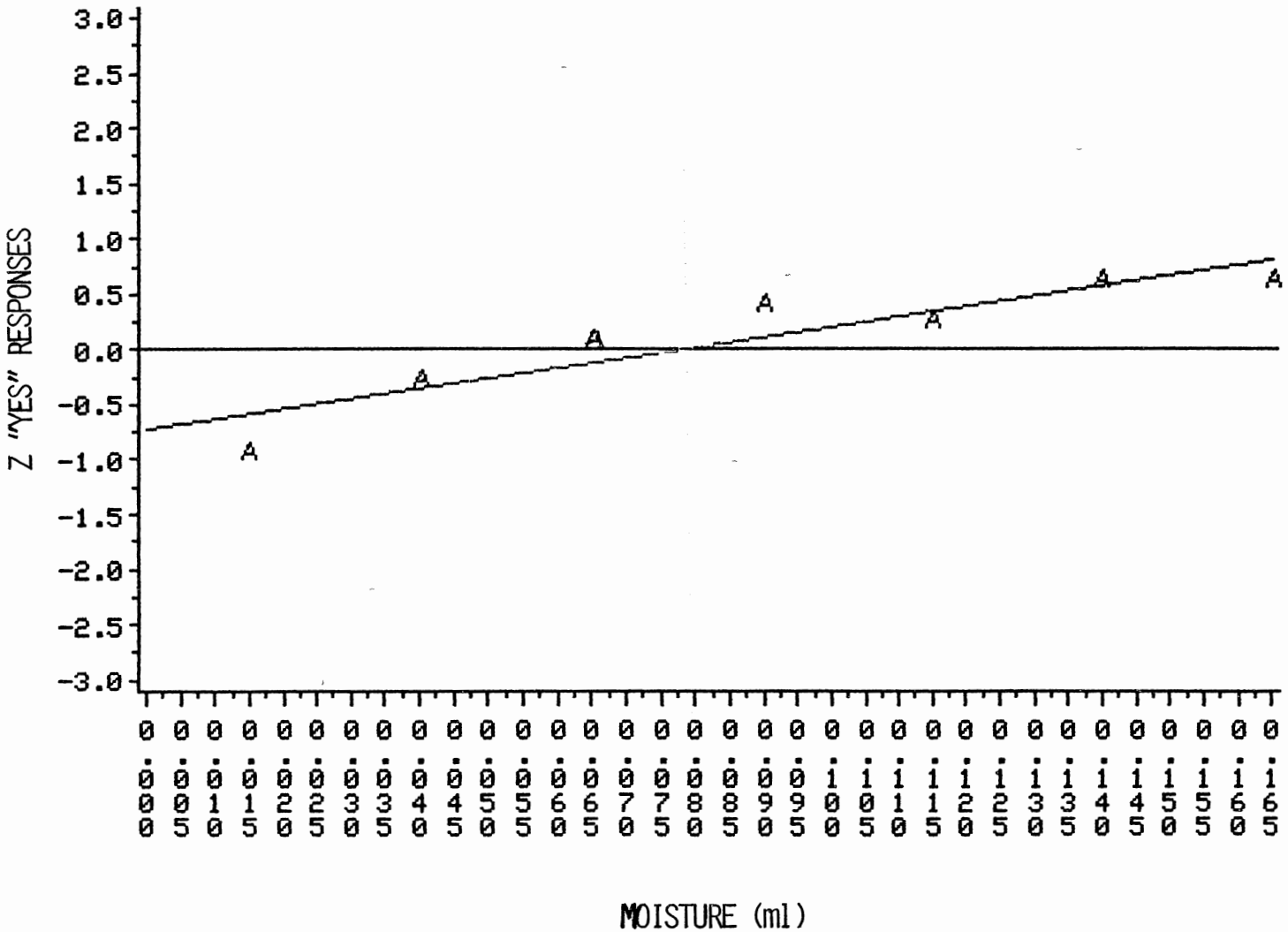
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
0.000
0.005
0.010
0.015
0.020
0.025
0.030
0.035
0.040
0.045
0.050
0.055
0.060
0.065
MOISTURE (ml)

APPENDIX I

FIT OF DATA POINTS TO DL REGRESSION LINES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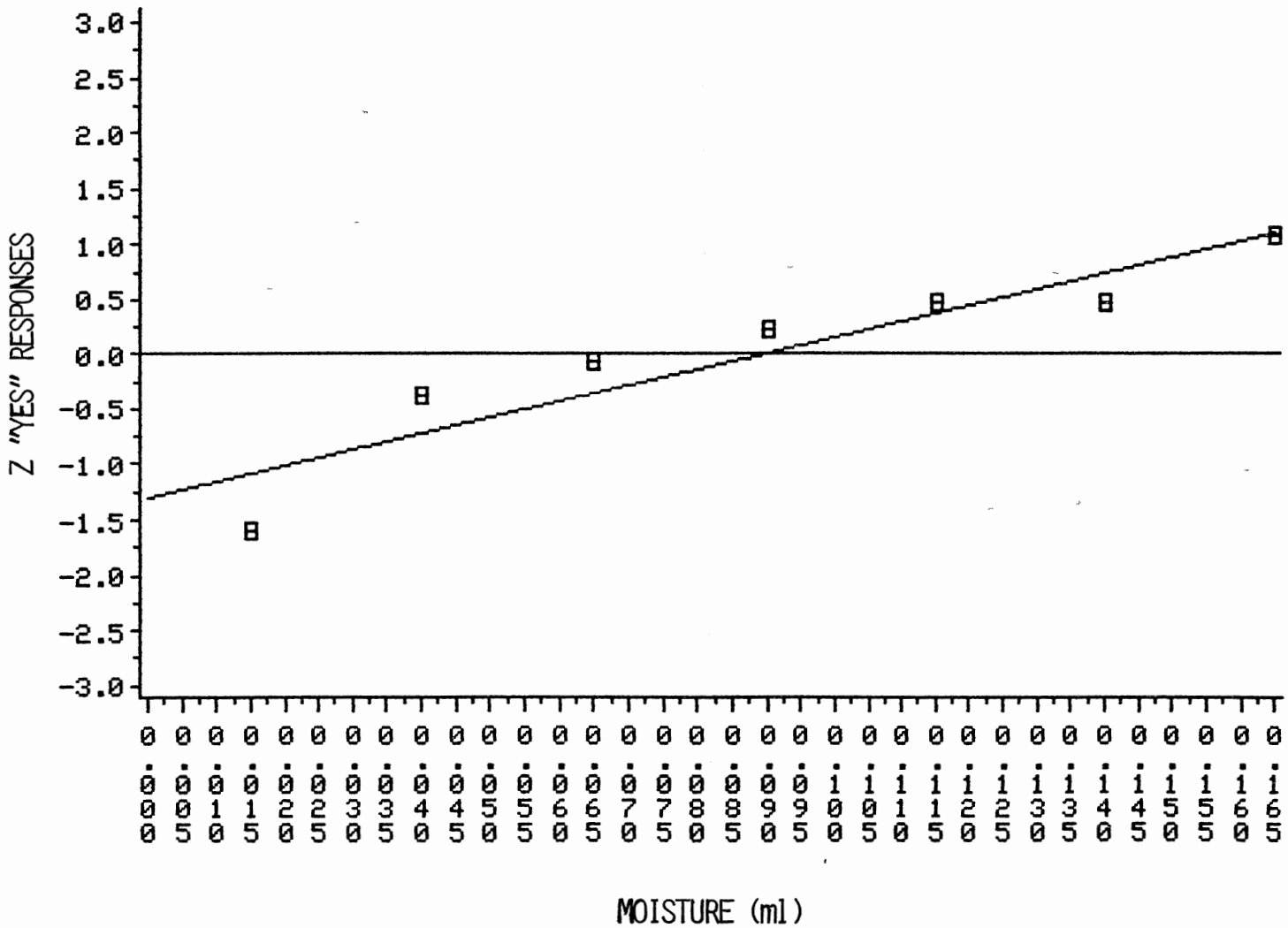
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
0.000
0.005
0.010
0.015
0.020
0.025
0.030
0.035
0.040
0.045
0.050
0.055
0.060
0.065
0.070
0.075
0.080
0.085
0.090
0.095
0.100
0.105
0.110
0.115
0.120
0.125
0.130
0.135
0.140
0.145
0.150
0.155
0.160
0.165
MOISTURE (ml)


Z "YES" RESPONSES
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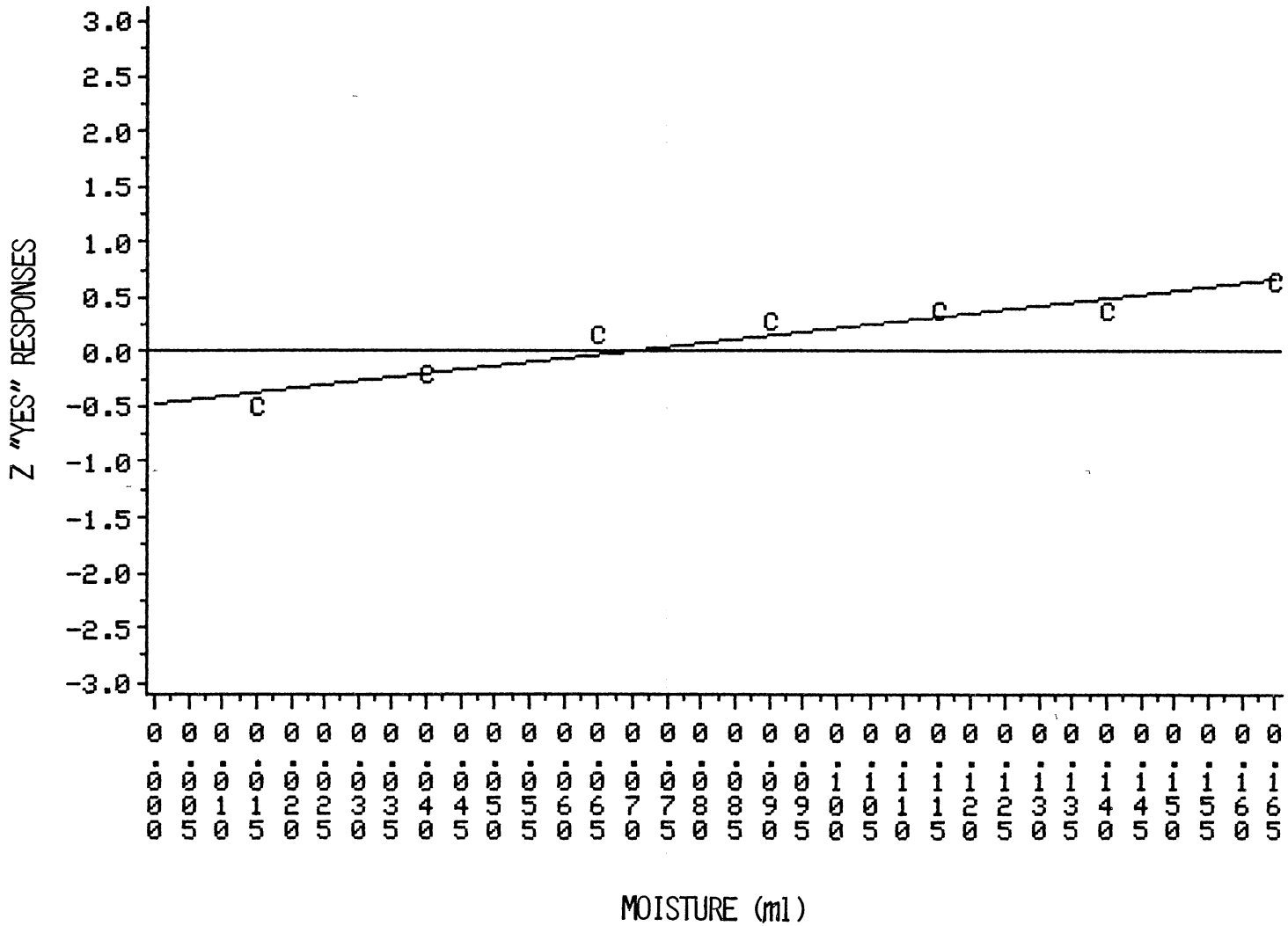
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
0.000
0.005
0.010
0.015
0.020
0.025
0.030
0.035
0.040
0.045
0.050
0.055
0.060
0.065
0.070
0.075
0.080
0.085
0.090
0.095
0.100
0.105
0.110
0.115
0.120
0.125
0.130
0.135
0.140
0.145
0.150
0.155
0.160
0.165
MOISTURE (ml)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1.0
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0.0
-0.5
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-2.0
-2.5
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0.020
0.025
0.030
0.035
0.040
0.045
0.050
0.055
0.060
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0.080
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0.100
0.105
0.110
0.115
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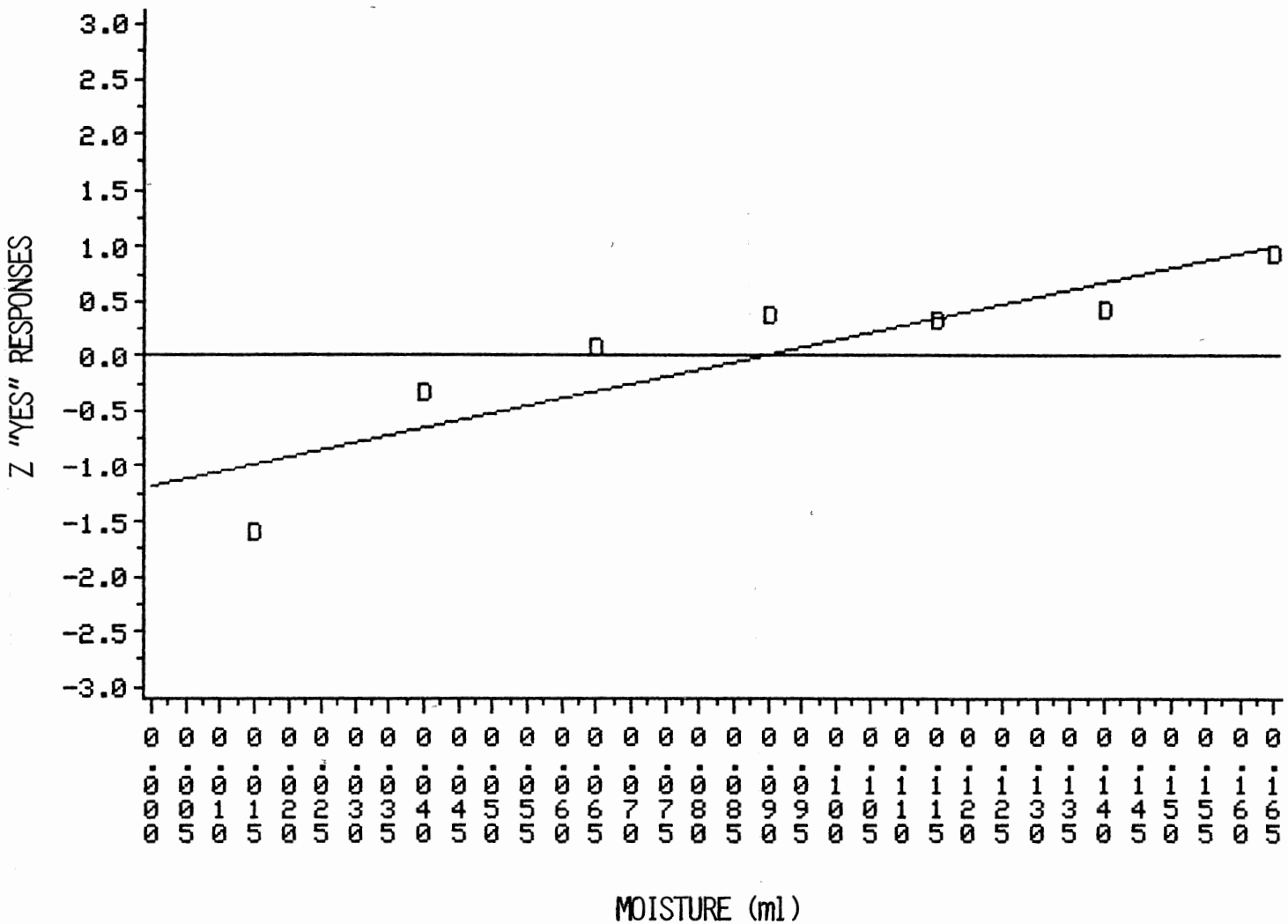
0.130
0.135
0.140
0.145
0.150
0.155
0.160
0.165
MOISTURE (ml)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-2.5
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0.005
0.010
0.015
0.020
0.025
0.030
0.035
0.040
0.045
0.050
0.055
0.060
0.065
0.070
0.075
0.080
0.085
0.090
0.095
0.100
0.105
0.110
0.115
0.120
0.125
0.130
0.135
0.140
0.145
0.150
0.155
0.160
0.165
MOISTURE (ml)

APPENDIX J

STATISTICAL TABLES

4 THROUGH 9

TABLE 4

ANALYSIS OF VARIANCE OF REGRESSION LINES FOR AL DATA BY FABRIC

Source	DF	Sum of Squares	Mean Square	F-Value	Prob.>F
Fabric	3	6.284	2.095	3.34	.036
Moist	1	46.094	46.094		
Moist*Fabric	3	1.894	.631		

*Mean moisture value = .0325 ml

TABLE 5

LEAST SQUARES DIFFERENCE COMPARISON TEST
FOR AL REGRESSION LINES

	Fabrics			
	B	D	A	C
Regression Lines	———	———	———	
			———	———

*All fabrics had the same mean of .0325 ml of moisture.
**Fabrics connected by a line were not significantly different.
***$p < .05$, DF = 3

TABLE 6

ANALYSIS OF VARIANCE OF AL VALUES BY FABRIC

Source	DF	Mean Square	F-Value	Prob.>F
Fabrics	3	.00029005	1.6478	.19454
Error	28	.00017602		

*AL values for fabrics A, B, C, and D, were .018, .025, -.012, and .021 ml

TABLE 7

ANALYSIS OF VARIANCE OF REGRESSION LINES FOR DL DATA BY FABRIC

Source	DF	Sum of Squares	Mean Square	F-Value	Prob.>F
Fabric	3	.734	.245	2.73	.071
Moisture	1	8.491	8.491		
Moisture*Fabric	3	.648	.276		

*Mean moisture value = .09 ml

TABLE 8

ANALYSIS OF VARIANCE OF DL
VALUES BY FABRIC

Source	DF	Mean Square	F-Value	Prob.>F
Fabrics	3	.0054837	4.22	.0157
Error	24	.0001299		

*DL values for fabrics A, B, C, and D were .072, .046, .098, .051 ml

TABLE 9

LEAST SQUARES DIFFERENCE COMPARISON
TEST FOR DL VALUES

	Fabrics			
	B	D	A	C
Threshold Values	.046	.051	.072	.098

*Fabrics connected by a line were not significantly different

**p < .05, DF = 24

APPENDIX K

JUST NOTICEABLE DIFFERENCES (JND'S) ABOVE THRESHOLD

JUST NOTICEABLE DIFFERENCES (JND'S) ABOVE THRESHOLD

In this study, the difference thresholds (DLs) were determined for fabrics A, B, C, and D to be .072, .046, .098, .051 ml (Chapter 4, Table 2). The DL is the smallest amount of physical stimulus required to produce a perceived sensation difference, termed the JND, from the absolute threshold (AL). The ALs were determined for fabrics A, B, C, and D to be .018, .025, -.012, .021 ml (Chapter 4, Table 3). Weber's law states that the change in stimulus intensity that can just be discriminated is a constant fraction of the starting stimulus intensity (Gescheider, 1976). This Weber fraction was found by dividing each fabric's DL by the standard stimulus value (.09 ml). Resulting Weber fractions for fabrics A, B, C, and D were determined to be 79.44%, 51.11%, 108.33%, and 56.11% and are graphically depicted in Fig. 18. Using these Weber fractions the number of JNDs above threshold was determined for fabric A as follows: .018 X .7944 + .018 = .032; .032 X .7944 + .032 = .058; etc... JNDs above threshold that correspond to stimulus values are presented in Table 10 (next page). This data is represented graphically in Fig. 19.

TABLE 10

JUST NOTICEABLE DIFFERENCES (JND'S)
ABOVE THRESHOLD

# of JND's	Fabrics A	B	C	D
0	.032	.037	-.025	.033
1	.058	.056	-.052	.051
2	.104	.085	-.108	.080
3	.186	.128	-.225	.125
4	.334	.194	-.469	.195
5	.599	.293	-.977	.304
6	1.075	.443	-2.036	.475
7	1.929	.669	-4.241	.741
8	3.461	1.011	-8.835	1.157
9	6.211	1.528	-18.407	1.806
10	11.144	2.309	-38.347	2.819

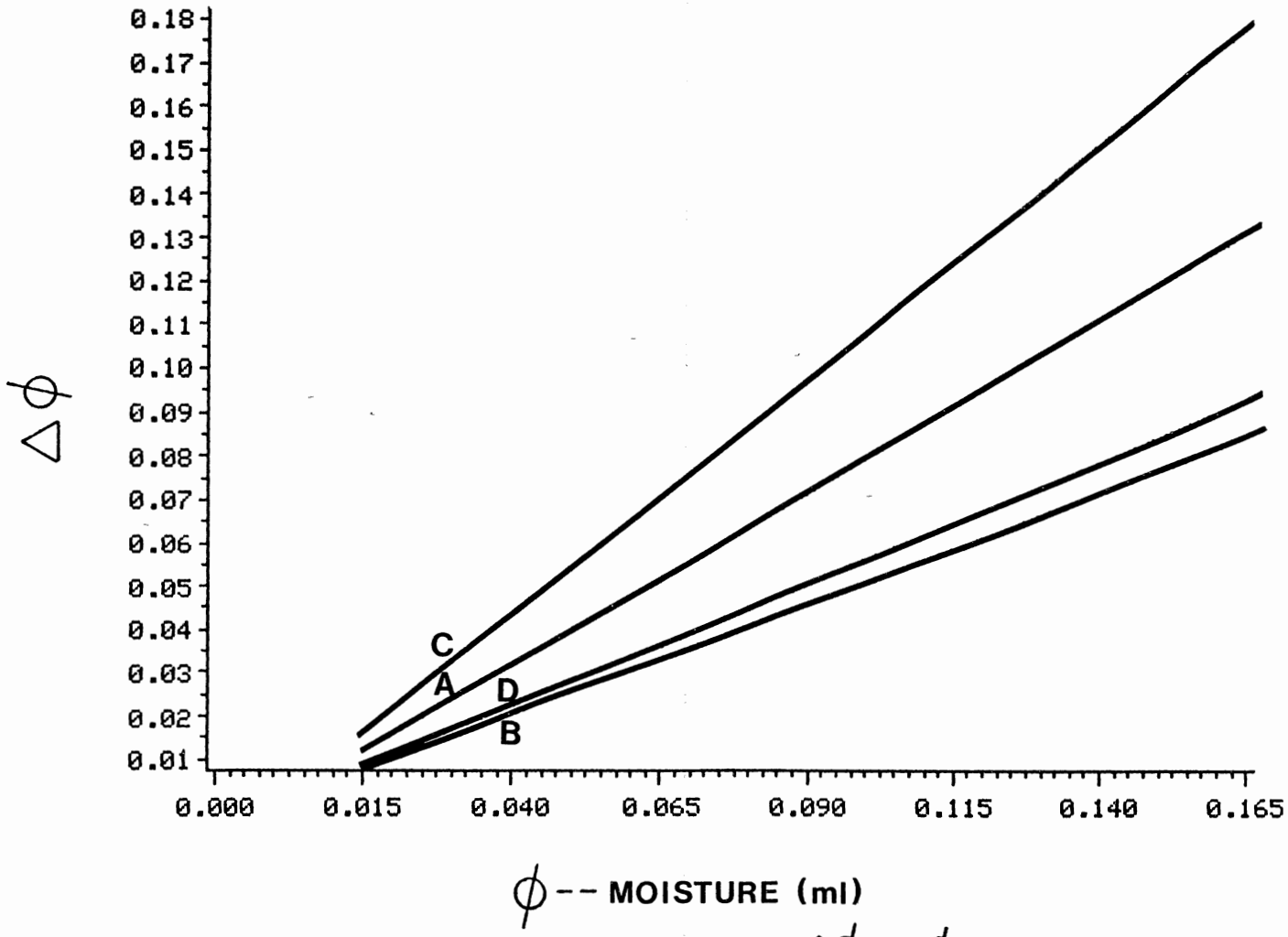

Figure 18. Relationship Between $\Delta\phi$ and ϕ According to Weber's Law.

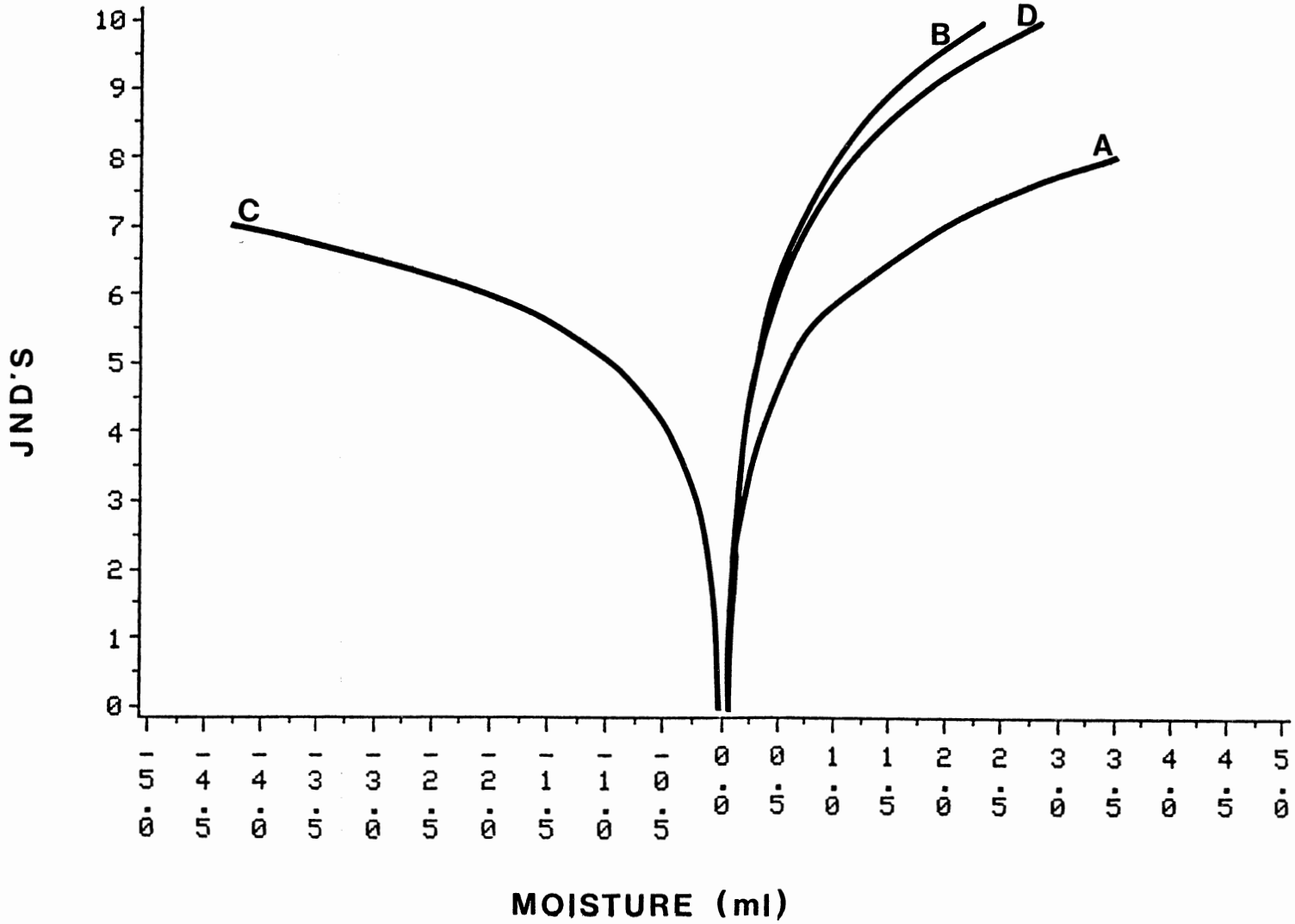

Figure 19. Number of JND's Above Threshold Plotted Against Stimulus Intensity.

VITA

Sharon Jean Weinzierl Mord

Candidate for the Degree of

Master of Science

Thesis: INFLUENCE OF FABRIC ON THRESHOLD DETERMINATIONS FOR MOISTURE SENSATION

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