

THE COMFORT DIMENSION; A REVIEW OF PERCEPTION IN CLOTHING

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ABSTRACT

For a clothing system, comfort is a fundamental necessity. In this paper, basic definitions and elements of clothing comfort and the general research trends were reviewed. In particular, understanding comfort of textile materials, its relevance to clothing choice and some assessment methods have been discussed. The impact of fabric and clothing attributes on clothing comfort was explored. Psychological, physical and physiological perceptions of clothing comfort were reviewed, including subjective and objective modes of assessment. A thorough discussion of handle comfort was presented, including assessment methods. Statistical presentations from selected comfort studies were also reviewed. Other sensory comfort properties particularly acoustic and appearance were also mentioned. From the aforementioned reviews, it was noted that the main focus for most researchers has been on sensorial and thermal comfort.

PRACTICAL APPLICATIONS

To comfort researchers, this review gives resourceful insights relevant to subject selection and the general research trend on clothing comfort. For clothing manufacturers, the compiled consumer feedbacks by wearers of particular clothing are tools for product improvement to enhance utility. Finally, this review informs consumers about clothing comfort, which will contribute to informed decision making during purchasing.

INTRODUCTION

Clothing is an essential human need with several functions. The choice of clothing is based on many factors such as personal desires and the particular application; which are user dependent. However, people's preferences may also be dynamic with seasons, environment, age and type of activity (Anand 2003). To the wearer, comfort can be qualified as one approach to evaluate performance of clothing. In this sense, fabric engineers and clothing designers ought to consider clothing comfort as a quality aspect contributing to total clothing performance and the user's satisfaction (Hatch 1993; Mukhopadhyay and Midha 2008).

People using similar clothing, in the same physical setting may experience different comfort levels. Hence, some models have been suggested to predict comfort response

using defined variables (Hollies *et al.* 1979; Wu and Fan 2008; Vassiliadis 2009; Tiwari 2010). With increasing consumer information and concern, there is equally growing market competitiveness and research partly enhanced by wearers' feedback on clothing comfort (Horridge and Richards 1984; Hes and Hu 2008). On the producers' side, these studies are useful aides, in predicting appropriate designs having in mind the material requirements and design elements in relation to the intended end use (Papkov 1981). For instance, for an outdoor jacket; the fabric type, and the nature and position of openings are important. During rest, the fabric plays the most important role, while, during activity, the design and location of openings is significant (Ruckman *et al.* 1999). We reviewed recent works relevant to clothing comfort; mainly including basic definitions, comfort models and the general elements in clothing comfort.

DEFINITION AND SCOPE OF CLOTHING COMFORT

Comfort may be defined as a neutral state in which an individual experiences no pain or discomfort (Hatch 1993). Comfort involves a balance of physiological, psychological and physical aspects between a person and the environment (Slater 1985; Hatch 1993). Clothing comfort is commonly associated with stimuli and sensations that garments feel with change in human activity and the microclimate (Lamotte 1977; Hollies *et al.* 1979). Rees (1941), related thermal compatibility to fabric surface contact dynamics. For apparel use, this idea was successfully explored further on fabrics, and published by Hock *et al.* (1944). Bogaty *et al.* (1956) followed the trend, studied the structure of blended fabrics in relation to hand, while Mehrtens and Mcalister (1957) focused on sensations perceived by wearers, for different kinds of fiber/yarn denier, concluding that denier had an effect on final sensations. A recent study by Liu (2012) found that although wearers consider factors like fit, workmanship, style, comfort, color, ease of care, durability/serviceability, hand, absorbance, cool/warm feeling, fashion and design during clothing garment purchase, comfort was the most sought, followed by fit. Zhang *et al.* (2002) noted demographic influence in casual clothing selection in native China but stressed that comfort came first. Home Economists Kaplan and Okur (2008) asserted that wearers looked for a cool or warm, and/or smooth feeling in clothing, compared to attention on care and laundry guides. The comfort preference is more to the physiological and physical feeling

than it is for psychological fulfillment (Ruckman 2005; Kaplan and Okur 2008, 2009).

MODELS OF CLOTHING COMFORT

Clothing comfort is a wide and complex phenomenon with several attributes (Branson and Sweeney 1991). There are many models designed to explain clothing comfort. A few will be considered in this review.

A model by Fourt and Hollies (1970) highlighted the relationship between clothing, the person and the environment. These three components were characterized by several variables, which included: rate of metabolism, body temperature, evaporation, DuBois surface area and heart rate. These characterized the wearer. Clothing was characterized by thermal insulation, air permeability/breathability, weight, thickness, wind resistance and surface area. Environmental variables were; relative humidity, air movement, temperature and radiant heat. Variables related to clothing comfort were singled out to define clothing comfort as a function of the wearer, clothing and environmental attributes. Basing on the previous model, Pontrelli (1977) designed a subjective assessment model for clothing comfort by introducing psychophysiological attributes, including; fit, style and fashion, end-use, tactile and aesthetic properties and occasion (Fig. 1). A *modifier* concept was also introduced, stating that the wearer sieves through the physical and psychophysiological elements using inner personal *modifiers* to establish a comfort level. Such *modifiers* may include: personality (like lifestyle, preferences),

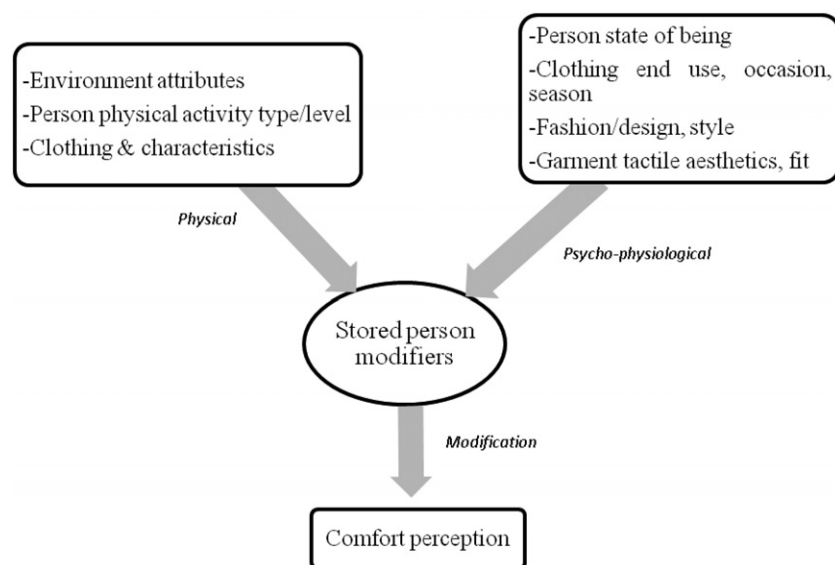


FIG. 1. INTERPRETATION OF PONTRELLI'S CLOTHING COMFORT MODEL
Adapted and reviewed from Pontrelli, F.J. 1977. Partial analysis of comfort's gestalt. In *Clothing Comfort: Interaction of Thermal, Ventilation, Construction, and Assessment Factors* (N.R.S. Hollies and R.F. Goldman, eds.) pp. 74, Ann Arbor Science Publishers, Ann Arbor, MI. Reproduced by permission of SAGE Publications.

previous experience, influence/prejudice and anticipations/expectations. The model was tested on several kinds of knitted wear, and results indicated that previous wearers' experiences and expected future performance of clothing had a significant effect on preferred tactile aesthetics in other similar wear.

These theories prompted another proposal by Sontag (1985) presenting the person's aspects at the center, surrounded by the clothing variables, which are also encircled by the environmental variables. Sontag's model lists elements associated with physiological, physical, psychological and social indicators of comfort in addition to their interrelationship (Fig. 2).

The model further suggests that the total comfort perception of clothing is also influenced by the physical and psychological aspects. These findings were similar to those reported by Black (1988), who however, added that physical comfort was more important, especially when higher temperatures are considered. Using Sontag's comfort model, it was concluded that petite and tall-sized wearers had more consideration for fit – a physical aspect, than attractiveness – a psychological aspect (Liu and Little 2009). Branson and Sweeney (1991) later suggested that clothing comfort has both physical and social-psychological elements, which affect a wearer's physiological stimuli due to clothing. The wearer's *filters*, such as previous experiences, anticipations and influence, together with the perceived response to the mentioned elements of comfort, give an individualized assessment of clothing comfort. In this comfort model, each element is dependent of and affects the other element.

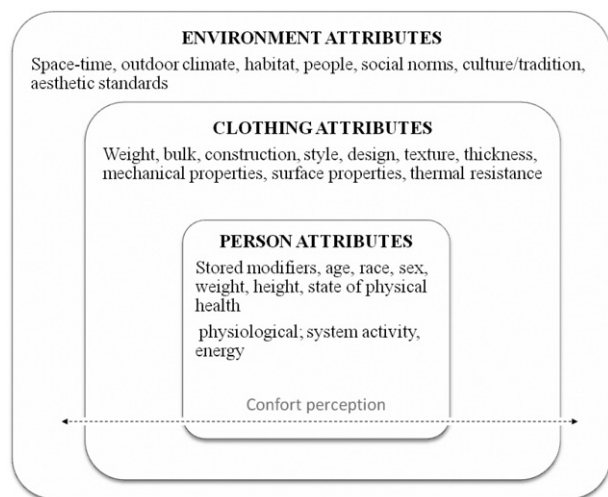


FIG. 2. SONTAG'S CLOTHING COMFORT TRIAD

Adapted and reviewed from Sontag, M.S. 1985. Comfort dimensions of actual and ideal insulative clothing for older women. *Cloth. Text. Res. J.* 4(1), 9–17. Copyright 1985, Wiley and Sons. Reproduced with permission.

These models have been used to generate systems of elements tailored to specific wear and function. To such effect, Liu and Little (2009) developed the 5Ps model (5Ps; physical, psychological, physiological, psychophysical and psychophysiological attributes) associated with an athlete's comfort and performance influenced by athletic wear. The model (Fig. 3) details a body-clothing-environment system, to optimize the design of an athletic wear with optimum function and comfort to improve performance. Depicting the mind-body connection, psychophysiological and physiological psychology interactions take up a joint section of the 5Ps, while, the outer layer shows typical sports conditions and the sports environment. Hence, the properties, sensations and interactions in this model, compound the clothing-body-environment, as mentioned earlier. The 5Ps model focuses on optimizing wearers' comfort and function by recognizing that the component elements do not act independently but jointly contribute to the overall user comfort and performance. Because most sports are held under dynamic conditions, the participant's body, mental working, wear and the close environment generate several complex and variable interactions.

Due to the change in physical properties of athletic clothing, the athlete develops a psychological response (psychophysical mechanism) and again, a physiological response due to psychological activities (psychophysiological mechanisms). These responses combined, will give a perceived comfort by the athlete (Bardhan and Sule 2001; The Hohenstein International Textile Research Centre 2007; Liu and Little 2009). The inner second layer caters for the engineering and design aesthetics such as style, openings, color, dimensions, panels design, fasteners and fit. These are in line with basic functional aspects of athletic clothing. To the outward, next is a design circle concerned with dynamic functionality and wearing properties, which are linked to the athlete's nature or condition, clothing property and their interaction with the athlete during active sporting.

UNDERSTANDING THE CLOTHING COMFORT DIVISIONS

Three basic classes have been broadly used to define clothing comfort, and include: *psychological/ergonomic, sensorial/tactile/physical and physiological* (Slater 1985; Mukhopadhyay and Midha 2008). Each aspect is important relative to context and preference. Also, each comfort aspect is influenced by a variety of attributes within the clothing-wearer-environment setting (Wong *et al.* 2003a,b, 2004; Kaplan and Okur 2008). It is important to classify and describe these kinds of comfort perceptions and their stimuli.

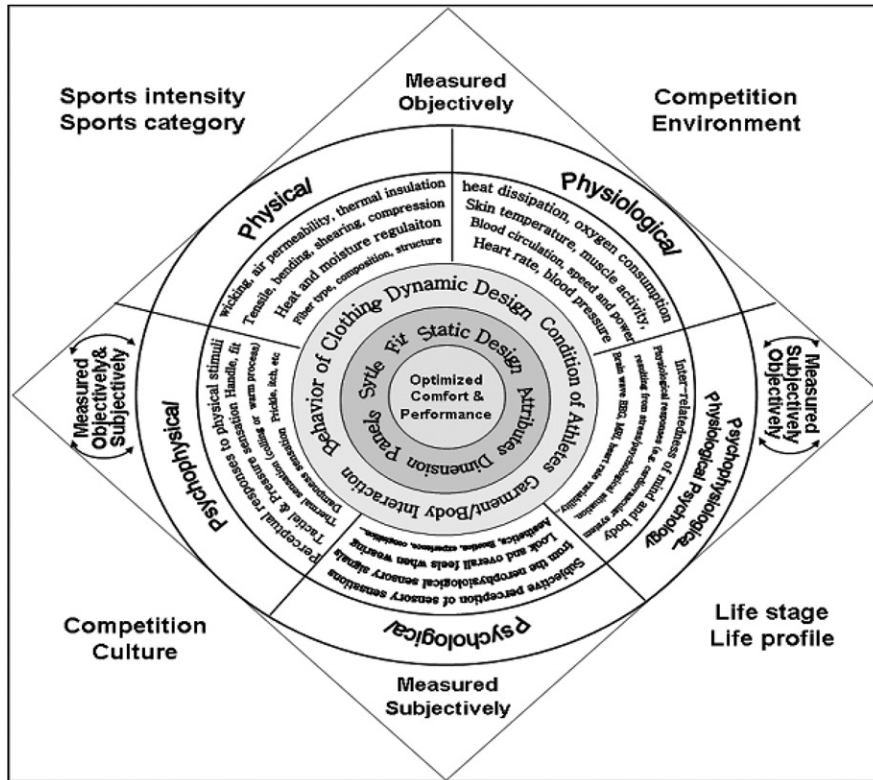


FIG. 3. USER COMFORT FACTORS PRESENTED IN THE 5PS MODEL Adapted from Liu R and Little T, JFBI 2(1), 41 (2009). Copyright 2009, The Textile Bioengineering and Informatics Society, Hong Kong, China. Reproduced with permission.

PSYCHOLOGICAL COMFORT

Psychological comfort focuses on the comfort of individuals in relation to their roles, values and social being. It is concerned with internal self consciousness and the value of life, related to satisfying oneself within choices available (Lamotte 1977; Horridge and Richards 1984; Hes and Hu 2008). The social-psychological spectrum, according to Branson and Sweeney (1991), involves *personal aspects* like body image, personality, cultural/religious/political values or beliefs, personal interests and awareness among others. And that also, there are *clothing attributes* related to details of the fabric and the clothing system. They include style, texture, aesthetics, fashion, suitability, design and color. *Environmental attributes* are also part of the psychological comfort zone, defined by elements like occasion, geographical location, climatic conditions, social-cultural settings and norms, and historical importance, to mention but a few. Wearers' past clothing experience, choices for fit, the desire for comfortable clothing and feelings about their body do affect psychological perceptions. Again, social/cultural values and the visual and tactile information affect the perception of fit, hence influencing the perceived psychological comfort level (Newburgh 1968; Hollies *et al.* 1978; Beatty *et al.* 1985; Shanley *et al.* 1993; Havenith *et al.* 2002; Yoo and Barker 2004; Chattaraman and Rudd 2006; Sular and Okur 2007; Gerhardt *et al.* 2008).

Results on the relationship between clothing aesthetic attributes and general body characteristics showed that wearers who possess a lower body image, and/or whose body size is large, feel more comfortable with clothing that offers much cover (Yoo and Barker 2004). It was also established that consumer behavior relates closely to their attitudes and values. For example; fashion preferences, cultural and personal values/preferences (such as feminine or masculine tendency, and individualism) influence consumers' modes and styles of clothing (Goldsmith 1988; Kaiser 1990; Kamakura and Novak 1992). Some wearers are hinged to values associated with fun and excitement; hence such would most likely take on fashion leadership than fashion adoption. With regard to sex and fit, it was reported that men rarely find fitting sleeve lengths. In the same study, relating garment with age, it was established that while elderly men prefer clothing made from man-made materials, it is the reverse for relatively young men. Elderly men were found to place more concern on clothing durability, while the younger men had more interest in garment design details (Ryan 1966; Goldsmith *et al.* 1991). Social-psychological attributes of clothing comfort will generally vary from person to person, influenced by individual decisions/choices for what they perceive as related to their preferences (Havenith *et al.* 2002; Kim and Farrell-Beck 2005).

A connection to the physical and physiological perception was done, with an argument that psychological comfort involves the brain activity, formulating subjectively, an overall perception of sensory sensations from neurophysiologic sensory signals through evaluation of several perceived sensations, judging by previous experiences and the person's inner wants (Havenith *et al.* 2002). Physical stimulus, the social and cultural environment, emotion, cognition and state of mind, among others are some factors that influence the psychological property of comfort. Physical stimulations also induce psychological and physiological responses between the wearer and clothing, while, psychological variations also induce physiological responses. These processes are cyclic; the induction of one induces another, accounting for total comfort perceived by the wearer (Liu and Little 2009; Wikipedia: The Free Encyclopedia 2012).

SENSORIAL/PHYSICAL/ TACTILE COMFORT

Sensorial comfort includes the various sensations toward discomfort by the wearer when clothing wholly or partially touches the wearer's skin (Kaplan and Okur 2009; Liu and Little 2009). During activity, physical stimuli from skin-clothing interaction stimulates various sensory receptors (as thermoreceptors, photoreceptors and mechanoreceptors), giving rise to a psychophysical perception. The term "fabric hand" usually applies when assessing the sensational property of textiles (Makinen *et al.* 2005). Fabric hand is critical to players in the textile value addition chain; from manufacturers to merchandisers, in the selection and development of textile materials, intended for use in apparel (Pan 2007; Yazdi and Ozcelik 2007). By touching cloth, we can feel *tactile sensations* like smoothness, roughness, prickliness, stickiness, scratchiness, softness and stiffness. Prickliness and itchiness reveal discomfort in form of pain. Thermal sensations can also be felt in the same way by touch, including warmth, coolness, breathability, hotness and chilliness (Bishop 1994; Dhinakaran *et al.* 2007). *Moisture sensations* are another hand perception, and they include among others; clamminess, dampness, wetness, stickiness, nonabsorbent and clingy. *Pressure sensations* which relate to body fit are another category, and may include snugness, looseness, lightweight, heaviness, softness and stiffness. The skin is said to be highly sensitive to mechanical stimuli, with a clothing pressure above 30 mmHg said to cause a sensation of discomfort (Liu *et al.* 2008), and that about 45 mmHg around the thighs likely to give a muscle *chemoreflex* response as exercising muscles accumulate metabolites (Moody *et al.* 2001; Liu and Little 2009). Other sensorial properties include: *acoustic* nature related to sound and hearing, visual or aesthetic perceptions (such as luster and fuzziness) and the odor characteristic. Some fibers have

natural smell or absorb and retain odors easily. This is typical of synthetics like polyester, and to a small extent, silk (a natural fiber). Wool (a natural fiber) has a natural antibacterial property by richness in fatty acids (Hatch 1993).

INFLUENCE OF FIBERS AND YARNS ON SENSORIAL COMFORT

The overall effect on sensorial comfort of clothing is a combination of several characteristics of each material(s) involved (fibers, yarns, fabric, finish and the wearer) (Behery 2005).

Fabrics made from 100% tough fibers like linen possess high bending rigidity and tensile resilience, while offering low shear rigidity and shear hysteresis magnitudes. Such fabrics are stiffer and also have higher surface friction. On the other hand, fabrics of 100% cotton, blends of cotton/linen, and viscose/cotton, or linen/viscose have relatively lower bending rigidity, in addition to a softer and smoother surface, and better resilience (Behera 2007; Shanmugasundaram 2008). The fiber structure and morphology definitely affect the yarns' aesthetic properties, and so for the fabrics, including friction properties (Supuren *et al.* 2010). Round-shaped fibers are said to exhibit higher luster compared to irregular shaped fibers and multidimensional fibers (Shanmugasundaram 2008). Also, with increase in fiber diameter, prickliness of fabrics does increase. Finer fibers yield smooth and flexible yarns and fabrics of better draping quality (Behera *et al.* 1998; Behera 2007). Higher fiber-to-fiber friction limits the ability of fibers to slide against or slide past each other during yarn and fabric deformation hence affecting the yarn flexibility. Fibers of higher crystallinity and alignment (such as linen) are generally tough and possess higher bending rigidities (Behera *et al.* 1998; Behery 2005). Prickliness is an undesirable sensation, common with coarse fabrics especially those that contain animal fibers such as wool (Bishop 1994).

Fabric bending, stiffness and shearing properties are affected by the *yarn twist*. Yarn twist also affects the aesthetic characteristics of the fabric, such as the appearance and feel. At high twist levels, the yarn is stiffer with less flexibility and deformability. High twist is susceptible to producing prickle sensations, and at times noise effects associated with some twill weaves. A rubbing effect could produce some sound/noise; common of the *crackle effect* which may not be desirable (Bishop 1994; Yazdi and Ozcelik 2007). Also, such yarns are less bulky, lack softness and have low surface friction (Behery 2005; Shanmugasundaram 2008). High twist levels give stiffer yarn which increases the bending rigidity. Some yarn modifications such as texturing, give yarn necessary bulk and stretch, and in turn the resulting fabric acquires a warm and soft hand compared to flat filament yarns, or even spun yarns (Mahar *et al.* 1990;

Behera 2007; Shanmugasundaram 2008). If not concealed by twist, the packing of fibers and linearity of fibers in yarn affect the sensorial qualities of a fabric. In this regard, yarns comprising more filaments are less stiff than yarns of fewer filaments, of the same size and fiber type. This stems from the fineness of the individual component filaments (Mukhopadhyay *et al.* 2002; Behery 2005). Yarn production methods do affect the tactile behavior of yarns. Particularly, cotton combed yarn is more even, dense and less hairy; offering fabric of a much lower coefficient of static friction when compared to rotor spun yarn. Similarly, yarns from air-jet spun yarn yield fabrics of appreciable thickness, less compression, more extensibility and stiffness compared to ring spun yarns (Behery 2005; Gerhardt *et al.* 2008).

FABRIC PROPERTIES AFFECTING SENSORIAL COMFORT

Fabric handle takes the largest aspect of sensorial comfort, and it is largely related to the basic mechanical and surface properties (tensile, bending, shearing, compression and thickness) of fabrics, involving small stresses. These mechanical properties contribute to stimuli perceived by the skin physical sensors. For example, low bending rigidity ensures a desirable tactile comfort perception (Bishop 1994; Mitsuo 2006).

The tensile behavior of a fabric is subject to its geometrical and structural configuration. A small load subjected to the fabric will make the constituent fibers to experience an inter-fiber friction, which also translates into yarn response in a similar style; either crimping or decrimping (Hu 2004). Mechanics of fibers show that fiber deformation proportionally varies to the third power of the fiber length, and indirectly proportional to the fourth power of its diameter (Hes and Hu 2008). Hence, fabrics comprised of microfibers will easily deform under pressure, partially imitating the body action. With finer and also protruding fibers, the contact area is relatively large allowing a high amount of heat to be given off from the body, giving a cool sensation (Slater 1977; Winakor *et al.* 1980; Hes and Hu 2008).

The bending response of fabrics affects the hang and drape of garments. Bending is influenced by the yarn bending property, fabric construction and the finish applied. Bending rigidity (resistance to flexing) and bending hysteresis (ability to recover) are two terms used to express the bending nature of textiles (Pavlinic and Gersak 2003). In functions where low curvature bending would be experienced (common in drapes), the energy involved in resisting the effect of friction is the hysteresis. Hence, viscoelastic properties of fibers/fabric would be necessary to note, in case of high curvature bending (Schwartz 2008). Some finishes such as enzyme treatments introduce disintegration and fibrillation, hence giving fabrics a cooling property

(high thermal absorptivity), usually accompanied by a sensation of smoothness and low bending rigidity. For good appearance, some garment parts like socks, skirt silhouette, pullovers and underwear need to have low bending rigidity. In contrast, some garments like men's suits, trousers, cuffs and collars require high bending rigidity (Lamotte 1977; Sular and Okur 2007; Hes and Hu 2008; Shanmugasundaram 2008). Clothing movement has also been explored as a sensorial aspect of clothing comfort, being related to fabric tactile attributes. Experiments on visual sensory perception of clothing movement showed that clothing visual attributes were highly related to fabric mechanical properties. Fabric drape, suggested as an estimate mode for clothing movement, correlated with visual and tactile attributes. Fabric weight was also found to be a major factor in determining drape of garments since it provides the bending force (Griffiths and Kulke 2002).

The shearing property of a fabric influences the ease of important fabric deformations and other aspects such as draping, pliability, stretch and handling of fabrics during use (Hu 2004; Schwartz 2008). With much body movement, the shear behavior allows fabric to conform to the shape of the body while wearing cloth, hence allowing good fit. This property depends on the yarn and fabric properties, allowing yarns to move against each other with each kind of fabric shear mechanism (Robinson *et al.* 1994). In this regard, loosely woven fabrics experience low yarn-yarn friction and allow for easy shear deformations compared to tightly woven fabrics (Pavlinic and Gersak 2003; Hu 2004). For knitted fabrics, the higher the stitch density, the higher the stiffness and thus the bending rigidity (Park and Hwang 2002). The *drape* of clothing, which is dependent on fabric bending and shear rigidity, is also influenced by the fabric mass. Good draping garments offer a comfortable perception, both physically and psychologically. The high shear/bending rigidity of paper and nonwovens explain their low draping quality (Lamotte 1977; Kim and Slaten 1999; Sular and Okur 2007). In nonwoven fabrics, it is complex to attain sufficient handle properties while maintaining the functional aspect of strength. This is because the need to increase strength by, say, more bonding increases the fabric stiffness. Yet, the comfort phenomenon is very paramount in such fabrics meant for sanitary products common for women and babies' needs. Blends, more open fabrics, and relevant finishes offer alternative means (Shanmugasundaram 2008).

For clothing fabrics, thickness and compression attributes are significant as far as handle is concerned. The thickness of a fabric tells about how warm, heavy or stiff a garment would feel while being worn (Brandt *et al.* 1963; Mukhopadhyay *et al.* 2002). A description of warm-cool feel is a common basic subjective description of fabric hand and sometimes, quality (Bishop 1994). Warm and cool

sensations are thermal features which relate to the heat flow between the skin and clothing. Roughness reduces the effective contact surface area, while smoothness increases the area of contact and thus the heat flow, which gives a cool hand. In inner garments, the transient heat flux greatly influences the comfort perception of the warm-cool feeling (Rees 1941; Saville 1999; Frydrych *et al.* 2002).

A variety of finishes are available to suit several end-use requirements for all kinds of fabrics. They are either mechanical or chemical. Fibrous surfaces can be conferred by raising or brushing, leading to a pile fabric with increased bulk and softness. Milling is commonly done on wool fabrics, with aid of scour liquors at high speed leading to improved specific volume and shear rigidity. Chemical treatments may include fabric softeners, stiffeners and enzyme finishing common on cellulose goods used to reduce height of protruding fibers. Softening involves softeners which lubricate the surface of the substrate thereby reducing the fiber–fiber friction. Some mechanical modifications like napping add warmth, since they create an irregular surface and more thickness, with lower mass. And with some surface fibers unsplit, and due to comparatively short length and larger thickness, these fibers are not easy to bend. Hence, such surface also has resistance to compression and possesses air pores that thermally insulate the fabric, leading to lower thermal absorptivity (Papkov 1981; Ruckman *et al.* 1999; Hes and Hu 2008; Le *et al.* 2012). Thermal treatments that facilitate fabric crimp are used to improve dimensional stability, bulk and stretch. Cotton fabric hairiness is reduced by singeing and cropping to give a smoother surface. Other smoothening finishes include: calendaring and decatizing which mainly work by flattening the fabric. Optical properties are improved by dyeing, printing, bleaching, calendaring, embossing and brightening, among others (Mamalis *et al.* 2001; Namligoz *et al.* 2008; Ozguney *et al.* 2009; Le *et al.* 2012).

Tactile comfort is not only limited to general hand but also to appearance, acoustic behavior and fuzziness among others. To evaluate fabric sound, analysis sound spectra can be obtained using Fast Fourier transform. Then, a comparison of the level pressure and level range for the total sounds, and frequency deviations of fabric sound, to mechanical factors established by the Kawabata Evaluation System can be done (Barker 2002; Mitsuo 2006). Another dimension of tactile comfort which should be considered is affect intensity. By studying consumer preference for different textile having different sensory attributes, Kergoat *et al.* (2012) reported that affect intensity plays a role in consumer soft textile preference. The aforementioned study involved car seats and shirts, cover both positive and negative emotions and was limited to fabric softness. More studies are likely to be carried out by other researchers covering more factors

and hence shed more light to the effect of affect intensity on other wide range of tactile comfort attributes.

SUBJECTIVE EVALUATION OF SENSORIAL COMFORT

Subjective analysis associates the hand of fabric to a psychological result due to the sense of touch (Bakar 2004). When fingers are run across the fabric surface, the person acquires series of sensory reactions, giving emotion and cognition within the mind. The perceived impression of the feeling is assigned to a particular hand parameter. Such a decision may be influenced by factors like; personality, environment, prejudice like anticipated or preferred result and previous experience, moods, criteria of ranking or scaling (Yick *et al.* 1995; Aliouche and Viallier 2000; Moody *et al.* 2001). Particularly, it is related to somatic sensory receptors, which are in charge of the body sensory analysis. These receptors relay information felt about texture, pressure, thermal reaction, elongation, tightness, softness and pain among others, depending on the style/technique of touch (Militky and Bajzik 1997).

With differences in sensory perceptions among individuals, it is not easy to reproduce results on the same textile judged by different people. The feel is also affected by external conditions (like sociological and physiological), even for the same person (Mahar *et al.* 1990; Bishop 1994). For example, females are said to possess more sensitive and delicate response to sensations compared to the male counterparts. Hence, females would give a finer evaluation for a parameter under judgment. Other possible social factors include age, culture, literacy level and other demographic factors. For a better evaluation, a wide panel of experts is preferred so as to give an integration of several results (Makinen *et al.* 2005; Hu 2008). Sensory and hand traits (such as stiffness, smoothness, thickness, bulkiness, roughness, prickliness, heaviness, looseness, bending/flexibility, appearance, drape-ability, surface friction, warmth, coolness, sheerness and snugness) are expressed on constructed scales, and assigned values or descriptors according to the degree of perception. Scales take an ordinal interval such as 1 to 10 or 1 to 5; 1 being very poor, while 5 and 10 correspond to excellent or very good (Mahar *et al.* 1990; Bakar 2004; Sular and Okur 2007). Handle assessment is a combination of sight and touch, and other conditions under which it is done. For example, touch sensations are stronger with high moisture contained on the skin (Bakar 2004). Specific patterns or strokes of touch (Fig. 4) can be used to assess particular details of the perception (Moody *et al.* 2001; Bakar 2004; Makinen *et al.* 2005). The touch-stroke method, which involves all fingers stroking the fabric surface, is used to evaluate surface details (texture) and thermal feel related to temperature. The rotating cupped

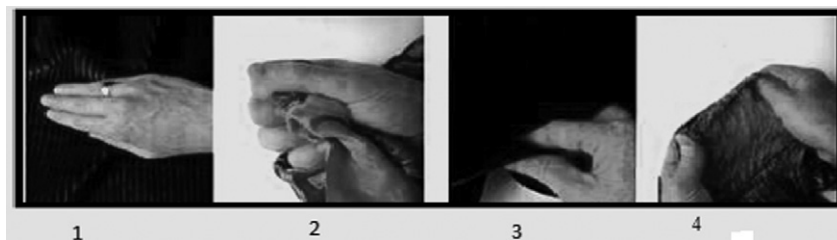


FIG. 4. HANDLE EVALUATION TECHNIQUES; 1- TOUCH STROKE; 2-ROTATING CUPPED, 3-MULTIPLE FINGER 4-TWO-HANDED ROTATION
Adapted from Moody, W., Morgan, R., Dillon, P., Baber, C and Wing, A. 2001. Factors underlying fabric perception. In the 1st Eurohaptics Conference Proceedings, Birmingham, 2001. Reproduced with permission.

method tests for comfort relative to stiffness, weight, resilience, temperature and texture. The multiple pinch action involves fabric being rotated between the thumb and one or two other fingers of the same hand to feel the stiffness, texture, structure, friction property, stretch and temperature. Finally, the two hand rotation seeks to evaluate the sheerness and stretch. While the influence of touch on the assessment of fabric handle is clear and has received some appreciable attention from researchers, the same cannot be said of sight. Findings by Yenket *et al.* (2007) indicated that fabric hand is not influenced by color. Therefore, the influence of the sight on the final results of handle assessment needs to be researched further before a clear conclusion can be drawn.

OBJECTIVE EVALUATION OF SENSORIAL COMFORT

Objective based methods by use of equipments offer the chance of consistency and reproducibility of results, hardly attainable with subjective methods (Hu 2008).

The Hand Evaluation and Standardization Committee of Japan recognized and developed the Kawabata's Hand Evaluation System for Fabrics in 1972. The method is based on scientific and empirical reasoning to measure mechanical and surface behavior of fabrics under low stress conditions. Measurable factors include: surface friction, bending, shear, and compression properties, which are decisive to handle comfort (Kawabata 1980; Makinen *et al.* 2005). A

total hand assessment relating to contributing elements is given in relation to fabric classification (such as cold clothing, summer clothing and undergarments) using relevant equations. The ranking scale has 1 for the lowest hand grade and a maximum of 5 for the best hand (Kawabata 1980). But, due to the fact that the system was developed from subjective assessment of a particular population, it was criticized as not being representative of a global population (Adanur 2001).

The Cantilever stiffness tester (Fig. 5a) is also used to measure fabric stiffness according to the ASTM D 1388 standard. The method involves uniformly feeding a flat horizontal strip of fabric between two parallel flat plates in the lengthwise direction. The fabric is allowed to deform under its own weight as it emerges at the tip of the plates. The bending length of the hanging fabric is measured when its tip meets the line making 41.5° with the horizontal from the upper plate edge (Fig. 5b). The flexural rigidity (G) is then computed from the formula: $G = 1.421 \times 10^{-5} \times W \times c^3$ whereby; G is the flexural rigidity ($\mu\text{joule/m}$), W is mass per unit area (g/cm^2) of the fabric and c is the bending length (mm) (Saville 1999).

Arising from contact between two surfaces, fabric friction is usually assessed by pulling a body of known mass over a uniform rigid surface covered by the fabric under test. In one method, a block of known mass (m) is involved (Fig. 6a). The weightless string to the block is connected around a frictionless pulley and to a tensile measuring device to record the force (F). The force that sets the block

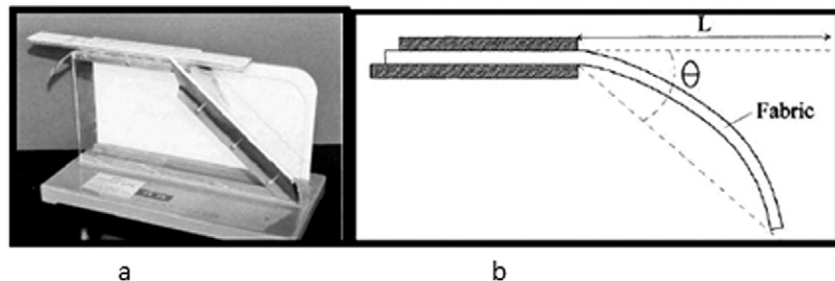
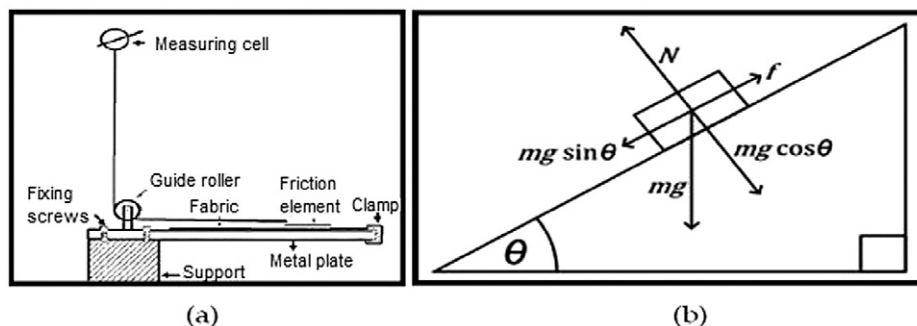


FIG. 5. A-CANTILEVER STIFFNESS TESTER; B-BENDING LENGTH
Adapted from Saville, B.P. 1999. Physical testing of textiles. Copyright 1999, Woodhead Publishing.

FIG. 6. BASIC FABRIC FRICTION MEASUREMENT METHODS (SAVILLE 1999). COPYRIGHT 1999, WOODHEAD PUBLISHING. REPRODUCED WITH PERMISSION



into motion corresponds to static coefficient of friction, while the force necessary to maintain motion corresponds to the dynamic coefficient of friction. In this case, the coefficient of friction, $\mu = F/(m.g)$.

In another method, the block covered with the test fabric is inclined as illustrated in Fig. 6b. The angle of inclination (θ) is gradually increased until the block just slides. At the moment of motion offset, the frictional force (F) is equivalent to the force due to mass m , parallel to the inclined plane ($mgsin\theta$) (Saville 1999).

A few other equipments for assessing sensorial comfort attributes include thickness gauges to evaluate thickness and compression behavior; the Shirley stiffness tester; draping meters for draping behavior (Saville 1999); the PhilaU Haptic Device used to give a touch/feel response (Govindaraj *et al.* 2003); and a robotic system by Potluri *et al.* (1995). By using such objective tailored methods, several models have been generated and found valid and relevant for estimating properties decisive for the handle of garment fabrics (Wang *et al.* 2012).

While sets of quantitative data can be generated for objective evaluation techniques, modeled relationships between subjective and objective methods have not been exhausted. Comprehensive modeling of subjective data has been limited by variations in and lack of precision in the scaling language, and absence of mathematical models to represent the complex nature of subjective evaluations (Zeng and Koehl 2003). Combining subjective and objective methods is better; wearers choose estimates from a given range of figures to give an average perception of stimulus arising from a tested comfort sensation (Cardello *et al.* 2003). The Handfeel Spectrum Descriptive Analysis (HSDA), proposed by Civile and Dus (1990), is based on defined operational elements to assess descriptive material-skin perceptions and ideally eliminates terms like poor, good and medium, by introducing a scale and ranks. This method has been revised and restated by the ASTM Committee E-18's Other Senses Task Group (E18.02.06.03). This psychophysical method can be compared with instrumental

results. For example, Cardello *et al.* (2003) used a combination of instrumental and numerical estimates of consumer verbal data on sensorial perception of selected military clothing. The use of multiple regressions to combine the two sets of data produced a better comfort level assessment and subsequent means of prediction.

The HSDA method comprises about 15 carefully selected and trained volunteer panelists. HSDA results are highly reliable and reproducible even over a long period of testing time apart (about half a year) (Cardello *et al.* 2003). Cardello (2008) also examined sensory handfeel using the HSDA method in a study of 13 fabrics used in US, British, Canadian and Australian military garments. Figure 7 shows a plot of the 17 HSDA sensory handfeel attributes of selected fabrics against the mean magnitude ratings for each attribute. The HSDA method enables useful profiling of sensory attributes of the fabrics for comparisons. For instance, from Fig. 7, compared to all other fabrics, the Canadian fabric rated very highly on aspects of "gritty," "fuzzy," "hand friction," "depression depth," "springiness" and "compressive resilience." The numerous attributes facilitate the differentiation of fabrics into several subgroups.

Similarly, Sweeney and Branson (1990) assessed the relationship between the intensity of moisture stimulus and subsequent moisture sensation at a particular body part. Although the respondents gave varying magnitude estimates of sensations, results showed similarity in the rank orders of moisture levels.

PHYSIOLOGICAL (THERMOPHYSIOLOGICAL/THERMAL) COMFORT

Physiological comfort relates to the body thermal regulation and coordinates between production and loss of body heat. Thermal comfort, as expressed by British Standard-BS EN ISO 7730, is "the condition of mind which expresses satisfaction with the thermal environment." Apart from the

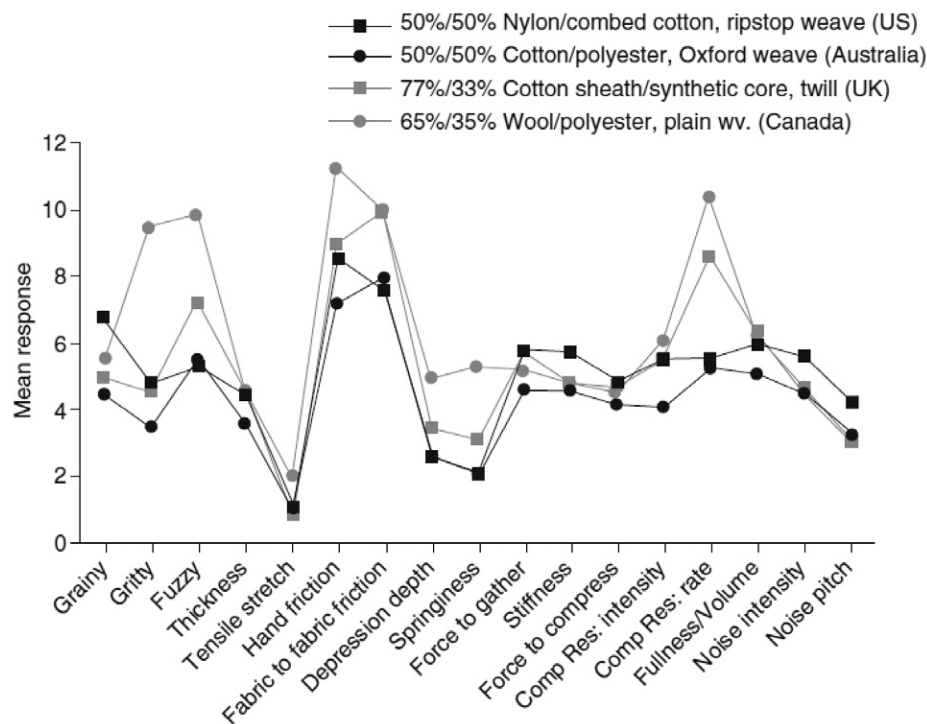


FIG. 7. AVERAGE RATINGS OF HANDFEEL ATTRIBUTES FOR FOUR MILITARY CLOTHING FABRICS Adapted from Cardello, A.V., Winterhalter, C and Schutz, H.G. 2003. Predicting the handle and comfort of military clothing fabrics from sensory and instrumental data: Development and application of new psychophysical methods of new psychophysical methods. Text. Res. J. 73, 221–237. Reproduced with permission.

environment, body physiological comfort is also dictated by body mechanisms such as pulmonary system, thermoregulation, central nervous system, cardiovascular system, skeletal muscular system and digestive system (Winslow *et al.* 1937b; Fanger 1970; Lamotte 1977; Parsons 1993; Havenith *et al.* 2002). In this work, the terms thermal comfort and thermophysiological comfort have been used to describe clothing comfort with reference to physiology.

Clothing systems contribute to attaining of equilibrium of heat and moisture exchange between the wearer's body and the environment (Robinson *et al.* 1994; Hes and Hu 2008). Thermophysiological comfort is more significant in outdoor clothing since they are worn for various physical activities and weather conditions (Rees 1941; Hock *et al.* 1944; Slater 1985). Hence, basic thermal comfort elements have been stated to include *environmental factors* (mainly – air and radiant temperature, air/wind velocity and humidity); *person elements* (including – clothing insulation, level of activity and work rate/metabolic heat flow); and *clothing properties* which relate to the fabric aspects, and garment design/make (Udabe 1958; Newburgh 1968; Slater 1985; Havenith and Holmer 2001; Li 2005; Qian and Fan 2006a,b; Das *et al.* 2007; Hes and Loghin 2009).

FACTORS THAT INFLUENCE THERMAL COMFORT OF CLOTHING

Metabolic Rate, Gender and Individual Attributes

Metabolic rates vary among individuals, and are more unstable with activity and surrounding conditions. The intake of foods and drinks influences metabolic behavior especially the rate which indirectly influences thermal responses. With high activity, high rates of metabolism are involved, and so more heating up. More heat is lost in a cold environment, as the metabolic rate increases to warm up the body. The physical body shape and size does affect thermal comfort through the surface area (Smolander 2002; Toftum 2005; Khodakarami 2009). The surface area to volume ratio plays an important aspect; for example, thin and tall people disperse more heat and can thus tolerate higher temperatures than round-shaped people because they possess a larger specific surface (Szokolay 2008).

High temperatures have been found to cause discomfort much earlier/more in men than in women, and the magnitude of discomfort expressed by men has also been noted to be higher compared to women. An evaluation of women

and men in the same cotton wear, performing a mental task reported that women felt more comfortable with relatively higher temperatures, contrary to men (Wyon *et al.* 1972). Further studies on the reaction to higher temperatures revealed that women were found to be more sensitive to temperature levels, while men were more sensitive to relative humidity (Karjalainen 2007; Lan *et al.* 2008). Some individuals possess unusual tolerance to thermal conditions due to age (the elderly and children), disability/abnormalities and illness. For instance, with age, people become less sensitive to hot and cold feeling. And, with age above 60, the thermoregulatory system of the body becomes less efficient and less effective as the responsible mechanisms become slower in response (Lenzuni *et al.* 2009). Wearers' thermal responses may be affected by individual behavioral and psychological aspects such as performance expectations and recent experiences (ANSI/ASHRAE 2010).

Environmental and Clothing Attributes

Contact with cool or warm surfaces such as floors may contribute to thermal discomfort of individuals. Hence, for footwear (such as socks and shoes) comfort, the actual contact surface thermal condition is more important than that of the material covering the floor. Also, the vertical temperature difference between the ankle area and that above the head level (a phenomenon, known as *vertical thermal stratification*) can generate thermal discomfort (Da-Silva *et al.* 2010). With climate varying from region to region, thermal comfort requirements become different too. For example, China's summers are hot and humid, while the winters are cold, calling for different clothing requirements compared to most tropical climates. Most urban areas are experiencing high heating levels arising from the depleted vegetation and tree cover (which would combat radiated heat), more housing with air conditioning (which generate heat), exhaust and engine heat from automobiles and industries among others. Clothing requirements due to this local heating cannot be adequately predicted due to constant changes (Shmaefsky 2006; Da-Silva *et al.* 2010).

Relative humidity creates a feeling of dampness or dryness especially indoor, depending on the extent. This has a role in influencing the perceived thermal comfort as it affects the skin moisture sensation. Compared to temperature, relative humidity is not effectively detected by the human sensory mechanism. Humidity levels between 30 and 60% are recommended for indoor environments (Balaras *et al.* 2007; Wolkoff and Kjaergaard 2007). For different body parts, the sensation of discomfort toward such dampness is also different. Hence, material requirements for clothing worn next to the skin must facilitate wicking or absorption (Fukazawa and Havenith 2009). Low relative humidity exposes wearers to thermal discomfort from dry

feeling, and also body itching. Thermal discomfort may also occur, in different magnitudes for specific locations of the body, due to localized heating or cooling in addition to air movement experienced at some locations (ISO 2005). *Draft*, is an unpleasant local cooling of the body due to air movement, experienced mainly during cool body sensation. This effect is felt more in uncovered body parts such as; the neck, legs, feet and shoulders. Draft sensation is influenced by air speed and temperature, activity level and clothing. The body heat equilibrium and comfort sensation for specific body locations have been computed (Zhang *et al.* 2009a,b,c).

The clothing insulating properties influence the thermal comfort experience of a wearer. With much insulation, heat loss from the body surface is minimal, and the body heats up more. This property is affected by the fabric material type, thickness, relative humidity and air or wind velocity (Havenith 1999; McCullough *et al.* 2009). Fabric made from wool fibers are known to have greater insulating properties, and are thus warm; hence they are preferred for winter. It is also similar for acrylics, piles and special fabrics made from textured yarn. Controlled ventilation, and layering in clothing is essential depending on the use (Fordham 2000; Omer 2008). Higher metabolic rates and/or more clothing insulation lower the thermal sensitivity of wearers, and thus lower exposure to thermal discomfort. Clothing may be adapted to serve under a maximum temperature indoor environment by altering the air speed so as to facilitate balanced heat loss from the skin. Considering an exercising wearer in light clothing; if the air speed is increased, the temperature within a comfort operation would also increase allowing active work to be done under high temperatures. However, high insulation would affect the result negatively (ANSI/ASHRAE 2010).

Advanced thermal comfort research in clothing is utilizing simulations to develop programs able to imitate environments in which clothing will be used so as to estimate a quantitative comfort level that would be perceived. Such models take into account the level of activity, metabolism rates and humidity levels among others. These have been utilized in programming Clothing Energy Simulation for technical clothing such as military and fire protection (Barwood *et al.* 2009). In this regard, a study on air-ventilated clothing was carried out to find better evaporative cooling in combat clothing. Intelligent textiles have also taken a great deal of research in the area of thermal comfort (Khodakarami and Nasrollahi 2012). ASHRAE standards give thermal comfort contributing factors, and specify the acceptable limits considering each aspect of thermal comfort.

Significant studies have pointed out effects of clothing discomfort on workers' performance. In nursing, it has also been noted that clothing comfort does affect patients'

response and so the healing (Adams and Keyserling 1996; Leung *et al.* 2008). Comfort requirements may also vary in patients of complicated illnesses; for example, low immunity-level patients, sensitive/reactive skin infections, and sores from burns, may need special clothing at particular times (Winslow *et al.* 1937b; Parsons 1993).

EVALUATING THE THERMAL BEHAVIOR OF TEXTILE MATERIALS

Qian and Fan (2006a,b) studied the comfort significance of thermal insulation and moisture-vapor transfer in the design of clothing systems. They wrote that to facilitate the body cooling process, garments should allow perspiration so as to pass out moisture. While, for minimal body heat loss, garments in contact with the wearer's skin should be dry. This is more imperative in clothing for neonates and hygiene dressings (Bergon *et al.* 1996). In wear for sports and protective functions, thermal resistance and water vapor porosity are the most important thermophysiological comfort requirements (Wong *et al.* 2002; Cardello *et al.* 2003; Yoo and Barker 2004; Leung *et al.* 2008). Papkov (1981) established that it is humidity rather than the outer layer of clothing that affects the evaporation process; low humidity increases evaporation rate. For significance in the evaporation process, clothing should be able to transfer moisture from the skin surface, through the inner side. Typically, surface contact angles below 90° will facilitate the moisture transfer process (Legendre and Meyer 2003; Ahmed 2010). Moisture is transferred through processes like diffusion, wicking, sorption and evaporation. Hence, hydrophobic materials may require some force, pressure or an opening to allow efficient skin-clothing moisture transfer (Newburgh 1968; Pontrelli 1977; Adler and Walsh 1984; Qian and Fan 2006b; Gerhardt *et al.* 2008). By assessing skin temperature and perspiration rates, Ruckman *et al.* (1999) explored some ventilation details in outdoor jackets, and their effect on thermal comfort. In a related study, Legendre and Meyer (2003) evaluated combined measurements of heart rate, oral temperature and sweat loss to ascertain the physiological response of work protective coveralls. The use of suitable ventilation was emphasized as very vital in combating thermal discomfort in these active wear. Simple and brief designs were suggested for sportswear, in addition to being of light weight, porous, air permeable, stretch resistant and appropriate fit among others (Adler and Walsh 1984; Ruckman *et al.* 1999).

There are limitations to efficient thermal assessment of clothing. Among them include the difficulty in assessing wet garments as fabrics get dry due to some long durations; lack of reproducibility of results even under same conditions; influence of uncontrollable factors such as sex,

age, diet, sleep pattern, activity before tests, and time of test; and the complex and costly nature of most tests (Udabe 1958; Barker 2002). Some tests are usually performed in dynamic environments and are not easy to control or harmonize (Benisek *et al.* 1987; Qian and Fan 2006a). However, there are also standard tests involving designed equipments and parameters to be assessed. They can be dynamic state tests or steady state tests, imitating changing and fixed environments respectively (Fanger 1970; Moody *et al.* 2001). Some standard test methods for clothing thermal comfort attributes include CAN/CGSB-4.2 No. 70.1-94 (Thermal insulation performance of textile materials); ASTM D 1518-85, 1990 (Thermal transmittance of textile materials); CAN/CGSB-4.2 No. 49-99 (Resistance of materials to water vapor diffusion); ASTM F1868-98 (Thermal and evaporative resistance of clothing); ISO 11092: 1993 (E) (Measurement of thermal and water-vapor resistance under steady-state conditions); ASTM E 96 (Water vapor transmission of materials); ASTM D 4772 (Standard test method for surface water absorption of terry fabrics; water flow test method); AATCC Test Method 79 (Absorbency of bleached textiles) (AATCC 2000; Qian and Fan 2006a; Das *et al.* 2007; Tiwari 2010).

QUANTIFYING COMFORT; SCALING AND RATINGS OF SUBJECTIVE PERCEPTIONS

Earlier methods and descriptors involved in assessment of perceptions of textiles (Binns 1926; Winslow *et al.* 1937a) were less logical, nor systematic. Even later improved theories (Fourt and Hollies 1970; Rohles 1971; Pontrelli 1977; Slater 1985) still had several limitations such as lack of defined attributes and improper scaling techniques among others (Civille and Dus 1990).

Category scales have been employed when carrying out psychological measurement. A 4-point category scale with comfort levels: "comfortable," "slightly uncomfortable," "uncomfortable" and "very uncomfortable," was designed by Gagge *et al.* (1967). Apart from having few scale points, criticism was also pointed to unequal levels in comfort and discomfort. The McGinnis thermal scale (Hollies *et al.* 1979) has 13-points for rating wearers' subjective perceptions, involving a couple of behavioral, sensory and affective descriptors. The range of levels runs from "I am so cold, I am helpless" to "I am so hot, I am sick and nauseated." Still, category scales have been criticized for among others; the tendency to have imbalance in intervals of perceptions and the limited use of the whole scale due to possibility of respondents avoiding giving exact perceptions they experience (Stevens and Galanter 1957; Gridgeman 1961). Borg (1982), Green *et al.* (1993) and Schutz and Cardello (2001) developed scales for measuring magnitudes of; perceived

TABLE 1. GEOMETRIC MEAN MAGNITUDE ESTIMATES, STANDARD ERRORS AND STANDARD ERRORS OF THE GEOMETRIC MEANS FOR THE SEMANTIC MEANING OF 43 DIFFERENT COMFORT-RELATED PHRASES (CARDELLO ET AL. 2003)

Comfort/discomfort word phrases	Geom. mean mag. est.	Standard error	Standard error/G.M
Greatest imaginable comfort	366.72	34.86	0.10
Greatest possible comfort	345.28	28.76	0.08
Exceptionally comfortable	280.20	16.03	0.06
Superior comfort	279.71	19.27	0.07
Intensely comfortable	268.44	19.82	0.07
Extremely comfortable	260.75	22.51	0.09
Highly comfortable	224.01	15.80	0.07
Very comfortable	202.99	13.96	0.07
Terribly comfortable	135.93	48.72	0.36
Moderately comfortable	130.18	10.51	0.08
Comfortable	109.22	10.81	0.10
Satisfactory comfort	86.11	11.68	0.14
Fairly comfortable	85.16	8.82	0.10
Average comfort	77.58	17.20	0.22
Acceptable comfort	72.17	8.85	0.12
Somewhat comfortable	69.98	9.07	0.16
Slightly comfortable	38.26	9.96	0.06
A little comfortable	28.77	7.82	0.27
Mediocre comfort	22.63	9.60	0.42
Barely comfortable	15.42	4.77	0.31
Neutral	0	0	N.A.
Neither comfortable nor uncomfortable	0	0	N.A.
Barely uncomfortable	-27.61	4.38	0.16
A little uncomfortable	-40.90	5.05	0.12
Slightly uncomfortable	-52.95	5.73	0.11
Somewhat uncomfortable	-71.56	6.74	0.09
Average discomfort	-76.64	13.55	0.18
Mediocre discomfort	-79.56	10.96	0.14
Uncomfortable	-98.34	8.21	0.09
Fairly uncomfortable	-99.30	10.07	0.10
Moderately uncomfortable	-145.63	7.23	0.05
Very uncomfortable	-209.86	11.00	0.05
Awfully uncomfortable	-228.96	10.71	0.05
Highly uncomfortable	-231.80	11.42	0.05
Terribly uncomfortable	-257.78	14.51	0.06
Exceptionally uncomfortable	-272.76	12.41	0.05
Intensely uncomfortable	-274.34	18.28	0.07
Oppressively uncomfortable	-278.70	15.71	0.06
Horribly uncomfortable	-283.88	22.86	0.08
Extremely uncomfortable	-290.84	15.57	0.05
Unbearably uncomfortable	-298.44	21.79	0.07
Greatest possible discomfort	-345.82	24.29	0.07
Greatest imaginable discomfort	-350.67	35.86	0.10

Bolded phrases are those used in Gagge *et al.* (1967) comfort sensation scale. G.M., geometric mean; N.A., not applicable.

exertion, oral sensations and liking/disliking, respectively. Based on these scales, and compounded with modern psychophysical methods, the Comfort Affective Labeled Magnitude (CALM) was developed at the US Army Natick Soldier Research, Development and Engineering Center (Cardello *et al.* 2003). It was established from a semantic study of comfort or discomfort levels described by 43 distinctive

words and phrases as rated by wearers in terms of magnitude estimates (Stevens 1957; Sweeney and Branson 1990). Cardello *et al.* 2003 summarized the average magnitude estimates, by subjects (Table 1). The CALM scale in Fig. 8 was then derived from Table 1. The scale is noncomplex, has high levels of comfort sensitivity and facilitates comparisons of different fabric perceptions percentages and ratios.

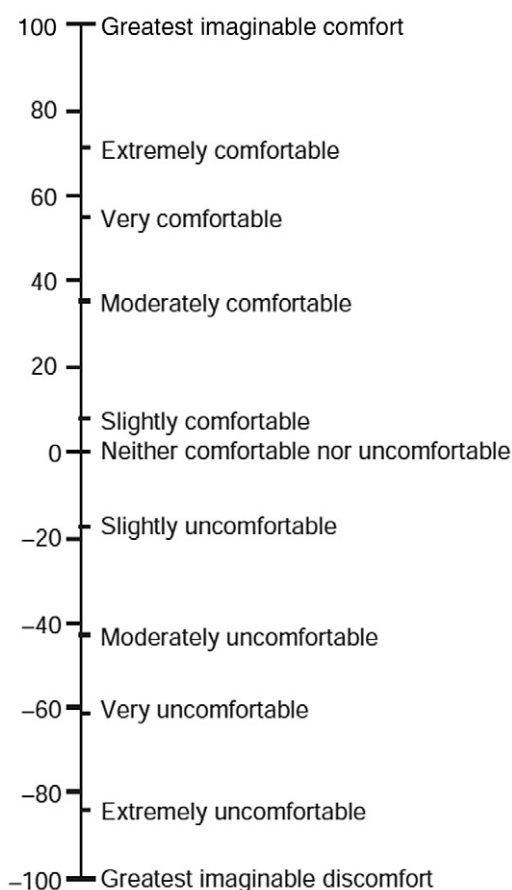


FIG. 8. THE COMFORT AFFECTIVE LABELED MAGNITUDE (CALM) SCALE

Adapted from Cardello, A.V., Winterhalter, C and Schutz, H.G. 2003. Predicting the handle and comfort of military clothing fabrics from sensory and instrumental data: Development and application of new psychophysical methods of new psychophysical methods. *Text. Res. J.* 73, 221–237. Reproduced with permission.

MEASURING PSYCHOSOCIAL PERCEPTIONS ABOUT FABRICS AND CLOTHING

Just like clothing attributes, wearers' attitudes, norms and beliefs, contribute to perceived comfort. Likert-type rating scales were employed by Workman (1990) to document attitudes and stereotyping toward fabric labeling. Considered labels included "cotton," "polyester" and "blended fabrics" among others. Consumer attitudes were rated and analyzed to establish how fabric labeling affected consumer preferences for jeans. Exploring wearers' attitudes toward silk, nylon and polyester meant for sport shirts and undershirts, Byrne *et al.* (1993) found a distinct and consistent attitude toward each fabric name. Forsythe and Thomas (1989) also found that wearers have clear attitudes toward

fibers and fabrics that have wide liking across several consumer segments.

Item by use appropriateness scaling, has been used in studying attitudes and beliefs toward fabrics and clothing (Schutz and Phillips 1976). The method involves a scaled rating of clothing based on how appropriate they are for particular cases/situations such as environment and specific applications. Using a sample of 15 fibers and fabric names, Schutz *et al.* (2005) used appropriateness scaling to examine military wearers' attitudes toward fibers and fabrics for military and commercial functions. An additional fabric branded as "ideal fabric" was also included. Using a 1–7 scaling (1 = "never appropriate"; 7 = "always appropriate"), the fibers and fabrics were assessed and rated on 30 selected attributes and uses as in Fig. 9. "Kevlar," "polyester" and "wool", which comprised the first group, were rated highly as "uncomfortable." "Polyester/cotton blends," "double-knit fabrics," "Nomex" and "synthetic fabrics" came next. The last group, which also included nylon/cotton blends used in military battle uniforms, had lower ratings on this property. The "ideal fabric" and "Gore-Tex" rated higher for "water resistant," followed by "Kevlar" and "nylon/cotton blends." "Denim" and "silk" had the least rating for water resistance. On the characteristics of "good in the desert," "cotton" and "nylon/cotton blends" had superior rating. For "good in the jungle," nylon/cotton blends rated much higher than cotton.

TABLE 2. PEARSON PRODUCT–MOMENT CORRELATIONS GREATER THAN 0.50 FOR THE ASSOCIATIONS BETWEEN KAWABATA HAND VALUES AND SENSORY HANDFEEL ATTRIBUTES AS OBTAINED IN THE STUDY BY CARDELLO *ET AL.* (2003)

Kawabata hand value	Handfeel attribute	<i>r</i>
Stiffness	Force to compress	0.83*
	Stiffness	0.80*
	Force to gather	0.79*
	Compression resilience: intensity	0.71
	Thickness	0.68
	Fullness/volume	0.63
Anti-drape stiffness	Force to compress	0.87*
	Stiffness	0.84*
	Force to gather	0.80*
	Compression resilience: intensity	0.73*
	Fullness/volume	0.71*
	Thickness	0.67
Fullness/softness	Springiness	0.87*
	Depression depth	0.85*
	Fuzzy	0.86*
	Hand friction	0.77*
	Gritty	0.76*
	Tensile stretch	0.67
Smoothness	Fuzzy	0.55
	Fabric to fabric friction	0.50
Crispness	No correlation	>0.50

* $P < 0.05$.

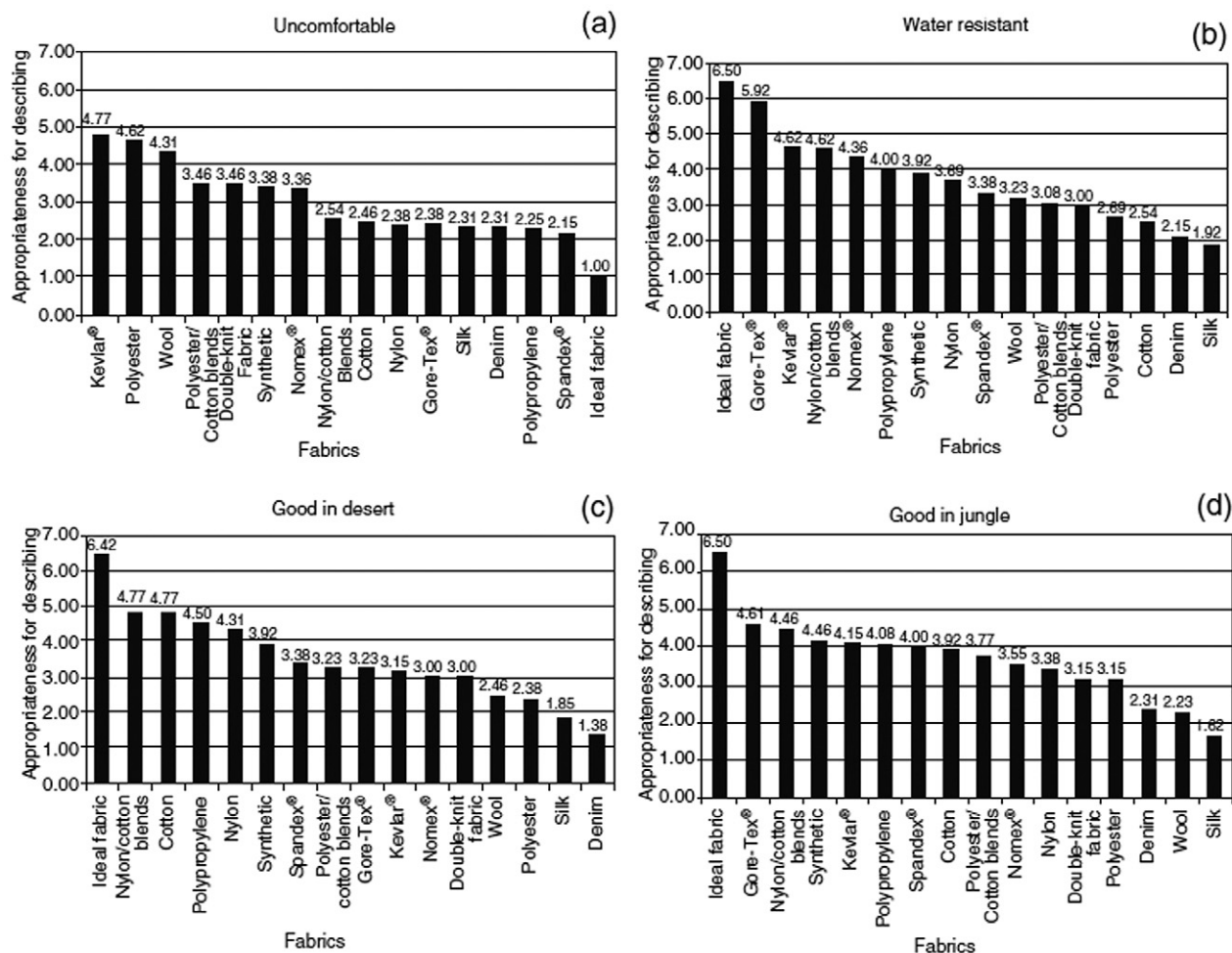


FIG. 9. MEAN APPROPRIATENESS RATINGS: (A) "UNCOMFORTABLE", (B) "WATER RESISTANCE", (C) "GOOD IN THE DESERT", AND (D) "GOOD IN THE JUNGLE" FOR EACH OF 16 FIBER/FABRIC NAMES

Adapted from Schutz, H.G., Cardello, A.V and Winterhalter, C. 2005. Perceptions of fiber and fabric uses and the factors contributing to military clothing comfort and satisfaction. *Text. Res. J.* 75(3), 223–232. Reproduced with permission.

This could be explained by the very low rating for cotton on appropriateness for water resistance.

Conjoint analysis is another study method for exploring wearing attitudes and beliefs of consumers. In this method, statistically designed descriptions of fabric attributes, lead to establishment of vital factors behind specific consumer attitudes and beliefs (Green and Srinivasan 1978a,b). The method enables understanding of relative importance of each attribute toward the wearers' choices (Crown and Brown 1984; Wagner *et al.* 1990; Eckman 1997). In a conjoint analytic study on two military body uniforms (temperate weather and hot weather uniforms) by Schutz *et al.* (2005), the important factors pertaining to comfort and satisfactions were listed during group interviews. The fabric attributes generated were: "abrasiveness," "clinginess," "absorbency," "softness," "breathability," "thick-

ness of the material," "weight of the material," "stiffness," "coarseness" and "thermal aspect" as in Fig. 10. Attributes for total clothing satisfaction were: "fit," "protection," "thermal comfort," "appearance," "durability" and "feel". A statistical model was then used to establish the worth of each factor level in terms of "utility value indexes;" hot weather comfort: $R^2 = 0.97$, temperate weather comfort: $R^2 = 0.99$, hot weather satisfaction: $R^2 = 0.88$, temperate weather satisfaction: $R^2 = 0.55$. Through analyses of variance, the researchers noted significant variations in ratings for each factor for both uniforms ($F = 20.68$; $df = 9.846$; $P = 0.001$ for hot weather; $F = 8.77$; $df = 9.846$; $P = 0.001$ for temperate weather). Further analysis showed that of all factors, thermal properties were more important for the comfort of the hot weather clothing than for the temperate; while "abrasiveness" was found to be more important

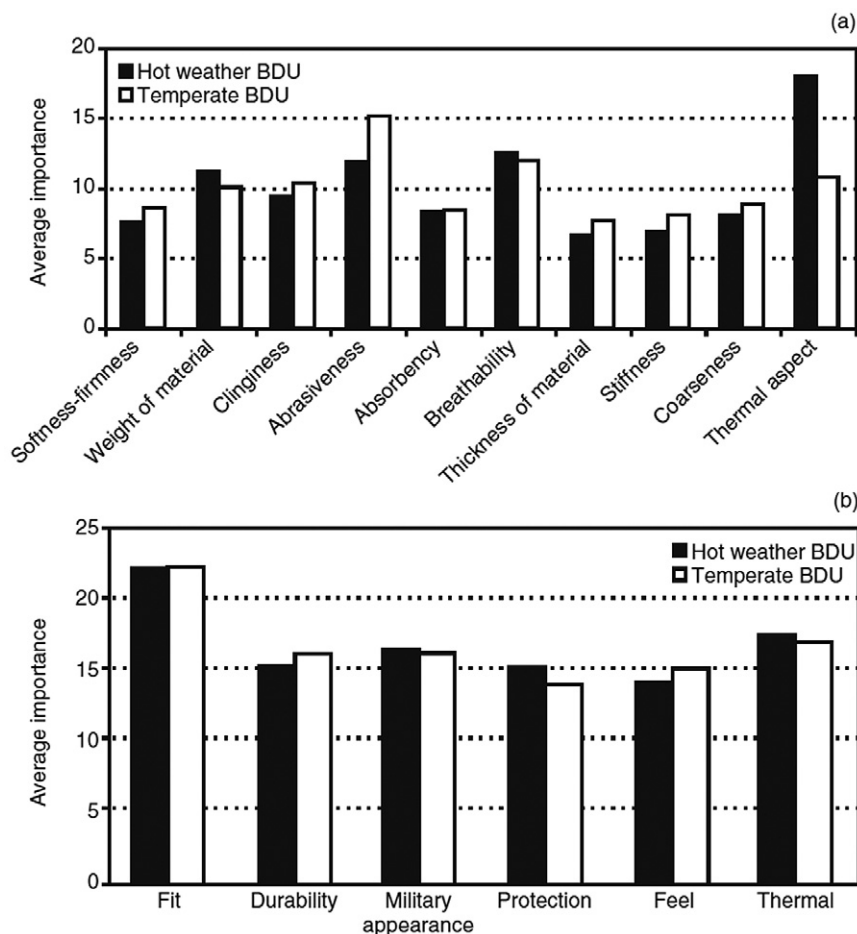


FIG. 10. AVERAGE IMPORTANCE VALUES FOR (A) COMFORT-RELATED AND (B) SATISFACTION-RELATED FACTORS FOR THE HOT WEATHER AND TEMPERATE WEATHER BDUS

Adapted from Schutz, H.G., Cardello, A.V and Winterhalter, C. 2005. Perceptions of fiber and fabric uses and the factors contributing to military clothing comfort and satisfaction. *Tex. Res. J.* 75(3), 223–232. Reproduced with permission. Reproduced with permission.

than all other factors to the temperate weather uniform than to the hot weather uniform.

STATISTICAL RELATIONSHIP BETWEEN SENSORY AND COMFORT ATTRIBUTES

To establish possible relationships among various comfort measuring techniques, Kawabata instrumental mechanical measurements were recorded (Kawabata and Niwa 1975; Kawabata 1980). Pearson product–moment correlation coefficients between the Kawabata hand parameters and the sensory handfeel ratings (Table 2) showed high correlation between specific Kawabata measured attributes and sensory handfeel attributes. Five important attributes: “shear,” “bending,” “compression/friction,” “tensile” and “surface

roughness” were identified by analyzing the Kawabata data.

A regression of these five Kawabata instrumental factors against wearers’ comfort ratings was done to estimate the comfort perception of the fabrics. The following equation was obtained:

$$\begin{aligned} \text{COMFORT} = & 11.8(\text{shear}) - 3.1(\text{bending}) \\ & - 0.3(\text{compression/friction}) - 11.9(\text{tensile}) \\ & + 0.4(\text{surface roughness}) \\ & + 27.5(R^2 \text{Adj} = 0.60). \end{aligned}$$

While, regression of the sensory handfeel factors against comfort ratings gave the following equation:

$$\begin{aligned} \text{COMFORT} = & -15.6(\text{surface texture/depth}) - 1.07(\text{volume}) \\ & - 7.67(\text{noise}) + 27.5(R^2 \text{Adj} = 0.87) \end{aligned}$$

Finally, a multiple regression model was obtained to give a sensory–instrumental–comfort relationship by combining both the sensory ratings and Kawabata measurements:

$$\text{COMFORT} = -16.3(\text{sensory surface texture/depth}) \\ - 8.7(\text{sensory noise}) - 4.3(\text{Kawabata surface texture}) + 27.5 (R^2 \text{Adj} = 0.96).$$

Thus, nearly all comfort deviation could arise from combined sensory and instrumental variables of the fabrics.

CONCLUSION

The comfort response of clothing influences overall performance and utility while in use. Hence, clothing comfort has attracted the interest of many researchers from textile and clothing, health, behavioral, military and thermal sciences. More concern seems to be directed toward active wear especially for sports, and protection, with a larger focus on the sensorial and physiological perceptions as the main integral elements in overall clothing comfort. Three main comfort attributes (psychological, physical and physiological perceptions) were discussed. Fulfilling all the three comfort attributes is not possible, hence a bigger effort is directed to functional needs of the clothing and then achieving an optimal combined comfort property.

Clothing comfort is a concept that can be defined and assessed in several ways, and can also be engineered into fabrics and garments. To maintain the body thermal balance, clothing should be capable of facilitating moisture vapor transfer to the surrounding environment. For example, several designs of breathable fabrics with multilayers of suitable materials, microfibers, nanofibers and super absorbing materials can be suggested for the interior. Hollow filaments, natural fibers, mesh linings and particular hydrophilic finishes are good examples of materials with good wicking properties. In work-wear such as overalls, controlled ventilation and openings facilitates this function. In sports clothing, breathable fabrics are particularly important. With textile innovations such as smart fabrics and clothing, we can expect interesting developments in clothing comfort related research. More research is needed in the area of textile accessories such as caps and hats, gloves and socks/stockings or, generally in footwear. In some sophisticated clothing like armory where the functional requirement is paramount, comfort is very difficult to achieve due to the need to maximize elements like cover and sometimes thickness. Finally, clothing comfort is not a naturally attained, but rather a result of evaluated combination of the wearer, environment and clothing attributes. Consumers will better their choice for clothing, by having a basic knowledge of textile materials used for clothing, their general characteristics and behavior under different environments. On the other hand, clothing producers ought to

utilize the knowledge of interaction of textile materials with the environment, and wearers, to engineer comfortable attributes into garments.

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