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Sports Apparel Warm and Cool Touch Effusivity Spectrums Based on Human Perception

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ABSTRACT

In the sports product industry, technical apparel materials can be developed to be perceived warm or cool to the human touch. Those created for warm touch are typically for cold environments - generating warmth for athlete comfort, whereas cool touch materials are developed for hot environments – making the athlete's skin surface feel cool and fresh. These attributes can be engineered into the face or back side of the material – providing different point-of-purchase and next-to-skin perceptual experiences. The goal of this study was to define warm and cool touch effusivity spectrums that the sports apparel industry can reference when developing new technical materials. The warm and cool touch characteristics of common sports materials were evaluated mechanically with a Modified Transient Plane Source (MTPS) sensor and perceptually with a human subject fingertip test protocol. From the data collected, cool and warm touch effusivity spectrums were determined for face and back material sides. For the face side of the material specimens, subjects' perception of warmth was at an average effusivity value of 145.9 (+/−23.1), and cool at 182.2 (+/−19.7). For the back side of the specimens, the materials were perceived warm at 138.6 (+/−22.6), and cool at 177.3 (+/−19.3). The results of this study provide sports apparel material developers insight into target effusivity value ranges for athlete warm or cool touch perceptual experiences.

Keywords: Warm touch, Cool touch, Effusivity, Sports apparel, Technical materials

INTRODUCTION

Recent technical material developments in the sports apparel industry have been focused on influencing human perception through warm or cool touch. Materials developed for warm touch are typically suited to cold environments - generating warmth for athlete comfort, whereas cool touch materials are developed for hot environments – to refresh the athlete's skin surface and feel cool. These attributes can be engineered into the face or the back side of the material, providing different point-of-purchase and next-to-skin perceptual experiences. Despite these technical advancements, there is a lack of standardization in the sports apparel industry of what quantitatively constitutes the perception of 'warm' or 'cool' touch. What are the guidelines for developers when innovating warm or cool touch materials for technical sports apparel?

The goal of this study was to define warm and cool touch effusivity spectrums that can be referenced by the sports apparel industry when developing future materials.

BACKGROUND

Measuring Effusivity

Effusivity is the scientific metric used to mechanically measure warm and cool touch. By definition, effusivity is the ability of a material to exchange heat with its' surroundings, also known as a material's thermal inertia (Blaine, 2018). Mathematically, effusivity is the square root of the product of the material's thermal conductivity and volumetric heat capacity (Blaine, 2018). Effusivity is measured with a device called the Modified Transient Plane Source (MTPS) sensor (Figure 1). At a high-level, the MTPS is a single sided, interfacial sensor that applies a momentary constant heat source to the material specimen being evaluated (CTherm, n.d.). Through this process, the rise in temperature that occurs between the sensor and the specimen, induces a voltage drop of the sensor element. This change directly determines the thermal effusivity value of the material specimen, therefore, defining its' warm or cool touch characteristics.

In detail, the rate of increase of the MTPS sensor temperature is inversely proportional to the thermal effusivity of the evaluated specimen (Sokolowski, et al., 2022). Therefore, in a MTPS measurement, the heat capacity of the sensor is omitted (Sokolowski et al., 2022). The reported value is solely a function of the thermal properties of the specimen, given by $e = \sqrt{\rho CK}$, where 'e' is thermal effusivity (Sokolowski et al., 2022). Although the MTPS apparatus does affect the heat flux of the system, the effect of the apparatus can either be separated out mathematically or through a calibration process (Emanuel, 2001). The MTPS sensor conforms to ASTM D7984: Standard Test Method for Measurement of Thermal Effusivity of Fabrics, which allows thermal effusivity values to be compared across systems and laboratories (ASTM, 2016).

Measuring Perceived Warm and Cool Touch

Despite the ability to mechanically quantify material thermal properties using the MTPS sensor, effusivity as a metric still lacks association with human perception. Tactile human perception as a measurement can be highly variable (Schneider and Feussner, 2017). In order to measure subjective thermal

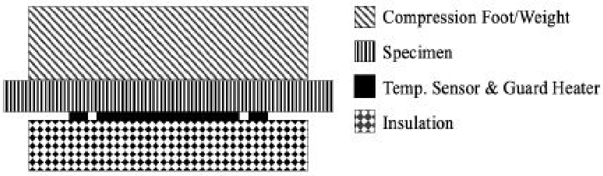

Figure 1: Modified Transient Plane Source (MTPS) sensor.

perception, a consistent protocol is necessary to establish methodological reliability between human subjects. Controlling subject contact with the specimens, visual bias, and environmental temperature are all factors that require consideration when regulating a perceptual experience.

To isolate haptic feedback and eliminate visual bias, it is recommended that subjects wear a blindfold, or have a blocked view of the textiles being evaluated (AATCC Technical Manual, 2007). Consistency must be provided in the instruction given to subjects on how to properly assess the textile swatches. It is recommended that the subjects use the fingertips of their dominant hand to contact the fabric swatch (AATCC Technical Manual, 2007). The fingertips and the thenar eminence of the palm have been identified as the most thermosensitive regions of the hand, where the individual is able to best discriminate between temperature differences (Stevens & Choo, 1998; Ho and Jones, 2006; Tiest and Kappers, 2009; Wongsriruksa et al., 2012). In order to prevent the transfer of body heat onto the textile surface, instruction on how to touch the fabric sample must be provided. Literature recommends that the subject contacts the textile using light strokes and taps for less than a 5 second period (AATCC Technical Manual, 2007). Other considerations to developing a human perception protocol to measure warm and cool touch include consistent preparation of specimens (e.g., same size, same mounting method), cleaning and sterilization of the hands, along with controlling hand temperature.

METHODOLOGY

Material Specimens

The materials evaluated in this study were provided by four global sports apparel industry partners, who asked to remain anonymous. The materials represented a wide range of sport apparel end-uses - including sweatshirts, wetsuits, T-shirts, base layers, mid layers, shirting, pants, and shells, across a broad scope of material constructions (knits and wovens) and finishes. In total, 37 materials were evaluated mechanically, using the MTPS sensor using ASTM D7984 to collect specimen effusivity, and perceptually, with human subjects performing the fingertip test protocol to determine warm and cool touch perception.

Effusivity Measurement Method

From the materials provided, 10×10 cm specimens were cut to collect effusivity data. When using ASTM D7984, the specimen thickness must exceed.10 cm, therefore, if multiple layers were required to achieve thickness, the cut squares were staggered such that no two contained the same yarn alignment. Before effusivity measures were collected, the material specimens and the MTPS system were conditioned to 21 ± 2°C with a relative humidity of $65 \pm 5\%$ for four hours according to ASTM D1776: Standard Practice for Conditioning and Testing Textiles (ASTM, 2020).

Thermal effusivity values were collected from the face and back sides of the cut specimens. Procedurally, each specimen was placed onto the MTPS sensor, and a fixed force load of 500 gF was applied to ensure consistent contact. Five consecutive MTPS sensor measurements were performed for each specimen using the Textiles I calibration. Three test sets were completed for each material. Between each test set, the specimen was removed and placed on the sensor at a different location to ensure precision of the data collected from the specimen. Results were then averaged.

For this study, the effusivity test method used assumed dry conditions and 1:1 fit of the apparel, as the specimens were not wetted or stretched during data collection. Face and back side effusivity measures were collected, as in the sports performance apparel industry both sides of the material are of importance to the consumer. The face side is the 'marketable' side of the material and can convey cool touch at retail when merchandise is displayed folded on a table or hung on hangars, whereas the back is the 'next to skin' side and is in direct contact with the athlete during sport (Sokolowski et al., 2022).

Warm and Cool Touch Fingertip Perception Measurement Method

To collect the warm and cool touch fingertip perception data, the 37 material specimens from the effusivity portion of the study were narrowed to 15 (face and back sides) to reduce human sensory overload. Through this reduction, careful attention was made to include a wide range of effusivity values, fiber contents, constructions, finishes and end uses. Because the effusivity values on the face and back sides of the materials differed, the selected 15 face specimens were not identical to the selected 15 back specimens.

The selected materials were laser cut into 20.32 × 27.94 cm rectangular specimens that were backed by identically sized paper cardstock. The backing helped to minimize the influence of test surface thermal conductivity during the perception test. A 1.6 cm paper cardstock bezel was also laser cut and attached to the face of each specimen to prevent material curling or fraying during human subject handling. This preparation was completed for all 15 material fronts and backs (30 specimens total).

Upon Institutional Review Board (IRB) approval, 30 human subjects were recruited to perform the perception component of the study. Subjects were between the ages of 18 and 35, with an equal percentage of male and female subjects. The age range was identified by the sports apparel industry partners and reflective of target users. Participants were also required to be recreationally active and regularly wear athletic apparel.

Upon arriving to the lab, signing consent, and being informed of the study procedures, the subject cleaned their hands with a disposable wipe, offering hand sterilization while standardizing hand temperature. The subject was then seated at the assessment table. To control the variability of cutaneous perception between subjects, several measures were put in place during the data collection protocol. First, subjects were given a blindfold to eliminate any visual prejudice associated with the material specimens. Secondly, they were instructed on how to properly touch the materials by using the fingertips of their dominant hand and tapping the specimen $t<5$ seconds to best perceive its thermality without transferring body heat onto the material surface. Once the subject was comfortable with the procedures, the warm and cool touch perception data was collected.

To collect warm touch perception data, the specimens were laid out from 15–1 (coolest to warmest in effusivity value), and the subject tapped on each material sample to determine when they started to feel warm. At the point when the subject felt warmth, the position (15-1) of the specimen was noted. This procedure was completed for face and back sides.

Similarly, to collect cool touch perception data, the specimens were laid out from 1–15 (warmest to coolest) and the subject tapped each one in order to deter when they started to feel cool. At the point when the subject felt cool touch, the position (1-15) of the specimen was noted. This procedure was completed for face and back sides.

RESULTS

Effusivity Data

The effusivity values collected with the MTPS sensor, along with descriptions and fiber content of the 15 selected material specimens (face and back sides) are presented in Table 1 and Table 2, respectively. Based on the measured effusivity values, the material specimens were then organized for the collection of warm and cool touch perception data.

Perception Data Participants

The sex and age characteristics of the 30 perception study participants are presented in Table 3. For this study, there was equal subject representation by sex. Participants aligned to the typical age range of human subjects studied in the sports apparel industry (e.g., 18–35 years). All participants reported that they were physically active and regularly wear athletic apparel.

Face Side Warm and Cool Touch Perception Results

When presenting the material specimens in order of highest effusivity (rank 15, coolest touch) to lowest effusivity (rank 1, warmest touch), subject perception of warm touch occurred, on average, between specimens 6 and 5 for the material face. This perception of warmth was associated with an average effusivity value of 145.9, with a coefficient of variation of 15.9.

When presenting the material specimens in order of lowest effusivity (rank 1, warmest touch) to highest effusivity (rank 15, coolest touch), subject perception of cool touch occurred, on average, at specimen 9 for the material face. This cool touch was associated with an effusivity value of 182.2, with a coefficient of variation of 10.8. For the fabric face, the identification of cool touch was at a lower coefficient of variation, suggesting improved perceptual precision between subjects.

Table 1. Specimen face details.

Specimen	Effusivity value	General description	Fiber content
1	54	Cotton/polyester fleece (sweatshirt weight)	65% Cotton, 35% Polyester
2	78	Cotton fleece (sweatshirt weight)	100% Cotton
3	109	Polyester double knit (top weight, textured)	100% Polyester
4	134	Polyester jersey with all-over sublimation (T-shirt weight)	100% Polyester
5	137	Nylon covered waterproof 3mm neoprene (wetsuit weight)	100% Synthetic Rubber Center, 92% Polyester, 8% Spandex Outer
6	156	Cotton jersey (T-shirt weight)	100% Cotton
7	159	Polyester woven (shirting weight, w/finish)	100% Polyester
8	181	Double knit polyester (base layer weight)	88% Polyester, 12% Spandex
9	191	Cotton woven shirting (shirting weight, w/o finish)	100% Cotton
10	193	Rayon jersey (T-shirt weight)	95% Rayon, 5% Spandex
11	195	Cotton jersey w/ spandex (T-shirt weight)	95% Cotton, 5% Spandex
12	196	Linen woven (shirting weight, w/o finish)	100% Linen
13	203	Cotton Demin (pant weight)	100% GRS Cotton
14	204	Nylon ultra-featherweight woven (shell weight, w/DWR)	100% Nylon
15	256	Cotton/polyester jersey (T-shirt weight)	61% Cotton, 39% Polyester

Back Side Warm and Cool Touch Perception Results

When presenting the material specimens in order of highest effusivity (rank 15, coolest touch) to lowest effusivity (rank 1, warmest touch), subject perception of warm touch occurred, on average, at material 4 for the material back. This perception of warmth was associated with an average effusivity value of 138.6, with a coefficient of variation of 16.3.

When presenting the material specimens in order of lowest effusivity (rank 1, warmest touch) to highest effusivity (rank 15, coolest touch), subject

Table 2. Specimen back details.

Specimen	Effusivity value	General description	Fiber content
1	98	Quilted polyester spacer (mid-layer weight)	100 Polyester
2	115	Cotton corduroy woven (pant weight)	99% Cotton, 1% Spandex
3	123	Polyester fleece (sweatshirt weight)	100% Polyester
4	152	Cotton jersey (T-shirt weight)	100% Cotton
5	152	Polyester jersey with all-over sublimation (T-shirt weight)	100% Polyester
6	165	Nylon warp knit mesh (top weight)	44% DL Nylon, 44% BT Nylon, 12% Spandex
7	167	Polyester woven (shirting weight, w/o spandex)	100% Polyester
8	180	Stretch polyester woven (pant weight)	90% Polyester, 10% Spandex
9	187	Stretch cotton Denim (pant weight)	99% Cotton, 1% Spandex
10	188	Linen woven (shirting weight, w/o finish)	100% Linen
11	209	Nylon ultra-featherweight woven (shell, w/o DWR finish, w/o PU film)	100% Nylon
12	210	Polyester team sport warp knit mesh (short weight)	100% Nylon
13	219	Heavyweight polyester circular knit (top/bottom weight)	82% Polyester, 18% Spandex
14	224	Nylon jersey (T-shirt weight)	100% Nylon
15	228	Nylon woven (shell weight, w/ PU film)	100% Nylon

Table 3. Participant sex and age characteristics.

Sex	18 to 25 years old	26 to 35 years old	Total
Male	10 subjects	5 subjects	15 subjects
Female	8 subjects	7 subjects	15 subjects

perception of cool touch occurred, on average, between specimens 7 and 8 for the material back. This cool touch is associated with an effusivity value of 177.3, with a coefficient of variation of 10.3. Like the material face, the identification of cool touch presented with a lower coefficient of variation than warm touch for the material backs, suggesting improved perceptual precision between subjects.

Effusivity Spectrums of Warm and Cool Touch

From the perception data collected, warm and cool touch effusivity spectrums were developed for the face and back sides of the evaluated materials (Figure 2).

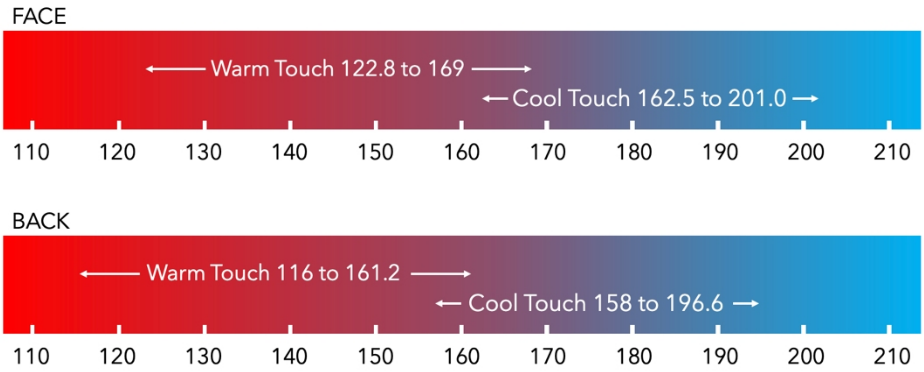

Figure 2: Face and back effusivity spectrums of warm and cool touch, based on participant perception.

From the effusivity spectrums, it can be noted that there were similar ranges of cool and warm touch perception for material face and back sides. It can also be assessed that the perceived range of cool touch compared to warm touch was more precise at 38.5 (face) and 38.6 (back), compared to the warm ranges of 46.2 (face) and 45.2 (back). This suggests that humans may be able to perceive cool touch better than warm touch.

CONCLUSION

Innovating performance materials to keep athletes warm or cool while training and competing is of great importance to sports apparel manufacturers. Metrics like warm or cool touch can be communicated as intellectual property and establish a point of difference at retail. The results of this study provide material developers reference target effusivity ranges that achieve warm or cool touch perceptual experiences for athletes.

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