Developing a holistic sensory evaluation three-part method for textiles and apparel: a practical application for novel materials and products

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*****Note: Table 1 can be found at the end of the document.**

Abstract:

Purpose This study aims to propose and demonstrate a practical application of a new three-part holistic sensory evaluation (HSE) method for textiles and apparel based on the senses of sight, touch, hearing and smell. HSE method development was carefully documented, described and successfully applied to evaluate sensory characteristics and consumer perceptions and acceptance of bacterial cellulose (BC), a novel sustainable material for apparel.

Design/methodology/approach In Part One of the HSE method, research participants described the material in their own words based on the senses of sight, touch, hearing and smell. In Part Two, they rated the intensities and their linking for 25 predetermined attributes describing BC. Part Three measured participants' overall liking of BC and its perceived suitability for apparel and accessories.

Findings Application of the HSE method resulted in an in-depth understanding of BC material. Areas for material improvements and positive characteristics were identified, providing direction for further development. Consumers found BC suitable for accessories and outer-layer garments but not for apparel.

Originality/value Sensory evaluation of textiles and apparel has traditionally focused on the senses of touch and sight. The new HSE method allows evaluating the full range of sensory characteristics of materials/products and holistically assessing consumer perceptions. The method is especially useful for novel materials and wearable technology. BC has gained increased interests as a novel sustainable material, yet consumer studies have been lacking. This study reports a comprehensive evaluation of BC material from consumer perspective.

Keywords: novel textiles | bacterial cellulose | holistic sensory evaluation method | sensory characteristics | product acceptance

Article:

Introduction

Novel fibers and textiles, biomaterials, solar cells, 3D-printed components and other unconventional materials are increasingly incorporated in apparel to meet the growing demand for innovative products such as smart textiles, wearable technology and sustainable products (Lehmann et al., 2018). These materials often have specific characteristics such as odors, sounds and textures that may evoke new and unusual sensations, affecting consumer attitudes, satisfaction and product acceptance. Capturing and evaluating the full range of sensory characteristics of novel materials and products as well as holistically assessing consumer perceptions become essential for adoption of such products. Research on sensory marketing and textile sensory analysis indicates the important role of sensory attributes in consumer product evaluation and purchase decisions (Nagamatsu et al., 2020; Tekin and Kanat, 2022). Understanding complete sensory profile of textiles and apparel is also important in online and virtual shopping environments, as providing complete sensory descriptions could improve consumer shopping experiences and outcomes (Jang and Ha, 2021). However, no methods exist for holistic sensory evaluation (HSE) of traditional or novel materials and apparel products.

Sensory evaluation helps to examine products based on the five human senses: sight, smell, taste, touch and hearing (ASTM E253-22a, 2022; Stone et al., 2013). However, sensory evaluation of textiles and apparel has traditionally focused on two senses: sight (visual characteristics) and touch, with tactile and thermal comfort receiving the most attention (An et al., 2013; Salerno-Kochan and Turek, 2021). In fact, the term sensory has been often used interchangeably with the tactile sensation in scholarly publications (Nagamatsu et al., 2020). Yet, apparel and other wearable products are also experienced through the senses of hearing and smell (Davis, 1996). For example, Nartker et al. (2022) found that consumers evaluated wearable assistive devices based on multisensory product aspects such as visual, tactile and olfactory cues. Products may embody odors due to specific fibers and materials used or because of added elements such as encapsulated essential oils. Wearable products may also make sounds due to use of plastic or metal components and fasteners such as snaps or Velcro (Davis, 1996). It should be noted that apparel products could also be experienced through the sense of taste, as they can touch the user's mouth or be directly chewed on, for example, by a baby or by a child with health or developmental conditions (Personal Communication, 2022).

In this paper, we propose and demonstrate a practical application of a new three-part HSE method for textiles and apparel based on four human senses: sight, touch, hearing and smell. The development of the method was carefully documented, described and successfully applied with 33 participants to evaluate sensory characteristics and consumer perceptions and acceptance of a novel sustainable material. Specifically, consumer perceptions of bacterial cellulose (BC) material and its suitability for apparel products and accessories were examined. The following research objectives guided the study to:

- develop a HSE method for textiles and apparel products guided by previous research;
- apply the developed method to examine how consumers perceive and characterize BC material based on the senses of touch, sight, smell and hearing;
- identify the areas for material improvement and the potential barriers and motivations for consumer acceptance of products made of BC; and
- evaluate acceptability of BC as a novel material for apparel products from consumer perspective.

Literature review

Sensory evaluation

Sensory evaluation is "used to evoke, measure, analyze and interpret reactions to stimuli perceived through the senses" (ASTM E253-22a, 2022). Stone et al. (2013) provide an appended definition that specifies: "… reactions to those characteristics of foods and materials as they are perceived by the senses of sight, smell, taste, touch, and hearing" (p.15). For conducting sensory evaluation, it is important to understand how sensory information is processed and is integrated in the brain (Stone et al., 2013). Each of the five senses has their own "unique receptors and neural pathways to higher and more complex structures of the brain" and, while "at the periphery, receptors for a specific sense respond to a specific type of stimulation that is unique to that system," at higher centers in the brain, "considerable integration occurs" (Stone et al., 2013, p. 18). This demonstrates that stimulations will not be exclusive to an individual sense. This principle is considered a fundamental component of sensory evaluation, and failure to account for it can lead to inaccurate evaluations. For example, requiring consumers to evaluate only one sensory attribute without controlling for the others can result in more variable and less sensitive responses as perceptions and evaluations related to the other senses will be embedded in these responses (Balaji, 2011; Stone et al., 2013).

Significant part of sensory analysis methods has been developed in the food sciences field; however, these methods have been increasingly used for non-food product evaluation (Moskovitz et al., 2008; Nagamatsu et al., 2020). Sensory evaluation methods are classified in three main categories: descriptive, discrimination and affective (Stone et al., 2013). Descriptive methods are used to describe and quantify sensory attributes of a stimulus by assessors, and discrimination tests are used for determining differences among two or more stimuli (ASTM E253-22a, 2022). Affective methods measure product acceptance, preference or liking (Phillippe et al., 2003; Stone et al., 2013). Traditionally, to ensure objective assessment of product characteristics, sensory evaluation has relied on extensively trained experts (ASTM E253-22a, 2022). Free-Choice Profiling (FCP) descriptive evaluation method developed by Williams and Langron (1984) has been used for sensory evaluation with untrained, "naïve" consumers (Deliza et al., 2005; Guardia et al., 2010). In this method, the untrained assessors evaluate products using their own descriptors or attributes characterizing the product. Attribute refers to a perceptible characteristic related to a product (ASTM E253-22a, 2022). Sensory attributes, often along with their intensity values, help to establish the sensory profile of a product, a description of its sensory characteristics (ISO 13299:2016, 2016). Developing a list of attributes or terms characterizing a product is a key step in sensory evaluation (Suwonsichon, 2019). To develop a list of attributes, generally, a panel of assessors evaluates samples representing the product, generates a list of terms characterizing the product, develops definitions of the terms and standard procedures for evaluation, identifies references clarifying the terms, then finalizes the list of the terms (Suwonsichon, 2019). Nagamatsu et al. (2018) conducted a study to develop a list of attributes or a lexicon for describing textiles using 20 various samples and 14 assessors, who described the samples using free vocabulary. The 299 attributes generated were reduced in four steps based on panel decisions, and after statistical analysis, 11 most significant attributes were included in the final list (Nagamatsu et al., 2018).

Sensory evaluation of apparel

Sensory evaluation of apparel products has generally focused on tactile and appearance properties (Balaji et al., 2011; Phillippe et al., 2003; Uren and Okur, 2019). Tactile comfort, particularly, has received much attention by researchers as one of the defining aspects of overall clothing comfort (Nagamatsu et al., 2020; Stankovic and Bizjak, 2014). "Tactile comfort relates to the mechanical interaction between clothing material and human body" (Stankovic and Bizjak, 2014, p. 203). According to Cardello et al. (2003), two fundamental dimensions of sensory experiences occur during the contact of human skin with clothing material. The first dimension relates to specific sensory attribute being experienced such as roughness and softness. The second is the intensity or magnitude of the specific sensations experienced such as extremely rough or very soft. Both dimensions should be examined for drawing conclusions about tactile sensory perceptions (Cardello et al., 2003).

Different methods have been used for measuring tactile properties of textiles such as AATCC EP 5–2020 guidelines for subjective evaluation of fabric hand, ASTM D6828-02 for measuring fabric stiffness (An et al., 2013) and Kawabata Evaluation System for Fabrics for testing fabric tactile properties based on its physical, mechanical, thermal and surface characteristics (Bacci et al., 2012). Phillippe et al. (2003) applied sensory evaluation techniques for descriptive sensory evaluation of various fabric types, and Harpa et al. (2018) used it to study the total handle of various wool fabrics. Kim and Hong (2019) applied sensory evaluation and psychophysical method in evaluating characteristics of thickness sensation. These studies focused only on tactile properties.

Salerno-Kochan and Turek (2021), used sensory analysis for quality assessment of clothing using a five-point hedonic scale. Acceptability of only sight and touch properties were evaluated, including product aesthetics, fabric composition, design/style, workmanship, additional elements and overall quality. Wagner et al. (2019) used sensory evaluation for design analysis for eco-fashion style, focusing only on product appearance.

To date, no studies conducting HSE of textiles and apparel products have been found. Given the increased importance of innovative fibers and materials, as well as rapid development of wearable technology and smart textiles and clothing (Lehmann et al., 2018), conducting HSE becomes essential for understanding consumer acceptance of novel products and materials. As nontraditional components are incorporated into apparel products, new methods are needed to capture and assess comprehensive sensory characteristics of products perceived by consumers. HSE could be used by scholars and industry to help gain valuable in-depth understanding about novel materials, product characteristics, consumer product evaluation and acceptance, including the advantageous properties and barriers to acceptance, leading to strategic product and marketing decisions.

Methodology

Instrument development

A three-part instrument for HSE method was developed, partly based on techniques used in FCP, a descriptive sensory evaluation method used for identifying product characteristics and qualities as perceived and described by product evaluators (Moskovitz et al., 2008). This method uses untrained product evaluators and allows them to use their own words to describe the sensory

characteristics of a product, then rate the intensity of those characteristics (Stone et al., 2013; ASTM E253-22a, 2022). In our study, the three-part HSE instrument was applied to evaluate consumer perceptions and acceptance of a novel sustainable material, BC, therefore, the wording of the instrument items reflected the material being evaluated. The HSE instrument can be easily adapted for evaluation of other materials. The three parts of the instrument, procedures for data collection, analysis and findings are outlined below, demonstrating the application of the instrument.

Part One: free-choice descriptions of material. In Part One of the instrument, participants are asked to independently generate attributes describing the sensory characteristics of a material or product they evaluate. In our study, 4 × 4 BC material swatches were evaluated. At the top of the page, a brief definition of sensory evaluation was included, followed by instructions for completing the task. Four columns, labeled sight, hearing, smell and touch, were provided to help participants think and generate attributes for these senses (Figure 1).

For each of the four senses, two synonyms were included for clarity. Participants were asked to examine the swatches and write down descriptions of the material in the appropriate sense columns. It was explained that there was no right or wrong answers, and participants were encouraged to provide descriptors to the best of their abilities. Such generation of material characteristics, or attributes is essential to sensory evaluation, because through them "we can understand how the panelist perceives the product" and "learn rather quickly why a particular product is acceptable or not acceptable" (Moskovitz et al., 2008, p. 173).

Part Two: rating the intensities and liking of material attributes. In Part Two of the instrument, participants were asked to evaluate the material by rating the intensities of 25 pre-determined material attributes on a scale of 0 (not at all) to 5 (extremely). In addition to the 25 attributes, spaces were provided for participants to add their own descriptors, if desired. Participants were also asked to indicate how much they liked or disliked each attribute on a scale of 1 (dislike) to 3 (like) (Figure 2).

The list of the 25 attributes was developed in advance by a panel of experts consisting of 6 textile science and apparel product development scholars. During the panel session, the experts examined the BC material swatches, then individually generated attributes to describe the material based on each of the four senses. In total, 93 attributes were generated with an average of 15.5 per expert. These included: 40 sight attributes; 33 touch attributes; 13 smell attributes; and 7 hearing attributes. Next, all 93 attributes were written on a whiteboard for further evaluation, categorized by senses. Based on discussions among the experts, redundant attributes were eliminated, similar ones were consolidated and consensus was reached on the final list of 25 attributes, which were used to develop Part Two of the instrument as described above (Figure 2). Eight of these attributes described the material's appearance; eight attributes described tactile properties; seven were smell-related attributes; and three were sound attributes (Table 2). It is recommended to develop a list of attributes specific to a novel material or product being evaluated if a suitable list is not found in the existing literature.

Part Three: overall liking and acceptability of the material. Part Three of the instrument measures overall liking and acceptability of the BC material for apparel and accessories. Participants were asked to indicate: (a) how much they liked or disliked the material (on a scale of 1 = dislike extremely to 5 = like extremely), (b) how acceptable the material was for clothing and (c) how acceptable the material was for fashion accessories (on a scale of 1 = not at all acceptable to 5 = very acceptable). Participants were also asked to provide additional comments about the characteristics or use of the BC material.

Sight (Appearance, look)	Hearing (Sound, noise)	Smell (Aroma, odor)	Touch (Handfeel, tactile)

Figure 1. Columns in part one of HSE instrument

	Indicate the intensity of each attribute for this material						Indicate how much you like or dislike each attribute for this material		
Attributes	Not at all					Extremely	Dislike	Neither like nor dislike	Like
Translucent, see-through	0	1	2	3	4	5	☐	☐	☐
Thick	0	1	2	3	4	5	☐	☐	☐
Heavy	0	1	2	3	4	5	☐	☐	☐
Soft	0	1	2	3	4	5	☐	☐	☐
Stiff	0	1	2	3	4	5	☐	☐	☐

Figure 2. Excerpt from part two–rating intensities and liking of material attributes

Data collection procedures and sample

A sample of 33 untrained research participants was recruited for the study at a large university in the USA. Each participant first completed a consent form, then a short survey to collect demographic information and data related to apparel shopping, including the number of clothing and accessory items purchased and approximate amount of money spent on these items over a typical three-month period. Next, the new three-part instrument described above was used to complete the sensory evaluation of the BC material. The printed instrument along with 4” × 4” BC material swatches were provided to participants for evaluation. The development and description of the material is outlined in Ghalachyan (2018). Participants examined the material as they completed the evaluation. The process took about 20 min. Each participant received a $5 coffee shop gift card.

Data analysis

Descriptive statistics were used (using SPSS software) to analyze demographic characteristics of the research participants, including age, ethnicity, year in college, academic major as well as apparel shopping data. Descriptive statistics were used to analyze the sensory evaluation data. For Part One of the sensory evaluation, the number of attributes generated by participant were calculated for each of the four sensory categories as well as the total combined. The average number of attributes per participant was also calculated. Frequencies were calculated for all attributes generated by participants. This helped to identify the high-frequency attributes, which were deemed as most important attributes identified by participants in describing the sensory characteristics of the BC material. For Part Two of the sensory evaluation, using SPSS, means and standard deviations were calculated for the intensity and liking ratings of the 25 attributes to

understand how participants perceived the BC material in terms of its sensory characteristics and particular characteristics they had liked or disliked.

For Part Three of the sensory evaluation, means and standard deviations were calculated for ratings of the overall liking of the BC material and the acceptability of the material for clothing and for accessories. Pearson correlation analysis was conducted, using SPSS, to examine whether the ratings for the overall liking of the BC material, acceptability of the material for clothing and acceptability of the material for accessories were associated with participant demographic characteristics (age, year in college) and apparel shopping habits (number of clothing and accessory items purchased and the amount of money spent on clothing and accessories).

Results

Participant demographic profile and apparel shopping habits

The research sample included 33 female college undergraduate (78.8%) and graduate (21.2%) students. Sophomores (27.3%) comprised the largest undergraduate group, followed by Juniors (24.2%), Seniors, (15.2%) and Freshmen (12.1%). The average age was 22, the range was 18–50 years and approximately 67% of the participants were of ages 19–21. The majority of the participants were White (69.7%), followed by Black/African American (12.1%), Asian (9.1%), Hispanic/Latina (6.1%) or another ethnicity (3%). Participants represented 21 academic majors. The number of participants from any given major ranged between one and four.

Over a typical three-month period, participants reported purchasing on average about eight clothing and accessory items ($M = 8.42$, $SD = 7.32$, $n = 33$), with a range of 0–35 items. On average, participants spent $145.30 on clothing and accessories ($M = 145.30$, $SD = 135.86$, $n = 33$) over a typical three-month period, with a range of $0–500.

Sensory evaluation

Part One: free-choice descriptions of bacterial cellulose material. In Part One of sensory evaluation, participants generated attributes describing the sensory characteristics of BC swatches, recording these under sight, hearing, smell and touch categories (Figure 1). These attributes were mostly one- or two-word descriptors such as “textured” or “organic-looking” or short expressions such as “looks like skin.” A few participants provided more detailed descriptions such as “sticky when rubbed against itself.”

For all sensory categories combined, 406 attributes describing BC material were generated. Senses of sight and touch accounted for 140 and 139 attributes, respectively. The smell category had 73 attributes and the hearing category had 54. During the analysis of these attributes, the same or similar attributes describing the same material characteristic were combined into one category to reduce and clarify the data. The attribute that best captured the meaning of each category was selected as the category name. For example, translucent, transparent and see-through attributes were combined into a see-through group because all described the fact that it was possible to see through the material. As another example, worn, weathered, antique-like, rustic, old-looking and distressed attributes were grouped into a worn-looking category. The result was 120 distinct attributes describing the sensory characteristics of the BC material. A total of 32 of these attributes were related to the sense of sight, 19 to hearing, 32 to smell and 37 to touch.

High- and low-frequency attributes. Attributes mentioned by at least 5 out of 33 participants (15%) were deemed high-frequency attributes for the purposes of this study to allow for a broader scope of attributes. A total of 27 out of the 120 distinct attributes were identified as high-frequency attributes. Attributes with frequencies between one and four, low-frequency attributes, were mentioned by fewer than 15% of the participants (by four or less participants). A total of 93 of the 120 distinct attributes were of low frequency, with the great majority having frequencies of one or two. The high-frequency sensory attributes are presented in Table 1 from highest to lowest frequencies, followed by a discussion. Low-frequency attributes are also briefly discussed.

Table 2. Intensity and liking ratings of BC sensory attributes, N = 33[a]

	Intensity rating		Liking ratings	
	M	*SD*	*M*	*SD*
Sensory attribute				
Sight				
Uneven color	*1.73*	1.35	2.24	0.65
Dull appearance	3.00	1.18	1.94	0.78
Non-uniform appearance	2.67	1.43	*2.36*	0.59
Leather-like appearance	*3.58*	1.21	*2.67*	0.59
Plastic-like appearance	2.58	1.44	1.86	0.74
Spotted, speckled	*1.59*	1.52	2.03	0.68
Wrinkly	*4.48*	0.93	*2.30*	0.80
Translucent, see-through	*4.39*	0.65	1.79	0.81
Touch				
Thick	1.79	1.34	*2.48*	0.66
Heavy	*0.91*	1.24	*2.58*	0.55
Sticky	*0.82*	1.14	2.00	0.83
Soft	1.94	1.43	*2.55*	0.70
Rough, textured	*3.48*	1.16	*2.42*	0.78
Stiff, rigid	1.91	1.40	*2.33*	0.72
Vinyl-like feel	2.81	1.42	2.03	0.63
Dry	*3.55*	1.52	*2.33*	0.64
Smell				
Vinegary-smelling	2.94	1.92	*1.48*	0.74
Spicy-smelling	*0.48*	1.02	1.97	0.80
Sweet-smelling	*0.91*	1.52	*2.33*	0.68
Pleasant-smelling	*1.33*	1.59	2.12	0.84
Overripe fruit-smelling	*1.39*	1.74	1.85	0.82
Ammonia/urine-smelling	1.79	1.75	*1.45*	0.74
Hearing				
Squeaky	2.03	1.61	2.00	0.74
Paper-like-sounding	2.73	1.60	1.81	0.58
Vinyl-like-sounding	3.00	1.44	1.91	0.57

Note: [a]Based on the intensity rating scale ranging from 0 (not at all) to5(extremely)and the liking scale ranging from 1 (dislike) to 3 (like)

Sight attributes. On average, participants generated 4.2 attributes related to the sense of sight, with a range of 2–10 attributes per participant. In total, 140 sight attributes were generated. Grouping the similar attributes (e.g. combining tan, beige, light brown, yellowish under tan), resulted in 32 final attributes describing sight characteristics.

A total of 7 were high-frequency attributes (see-through, tan color, wrinkly, skin-like, textured, worn-looking and natural) and 25 were low-frequency, related to the material's structure and appearance (e.g. mottled), perceived performance (e.g. fragile) and resemblance to other products (e.g. leathery).

The see-through attribute was the most frequently referenced sight attribute, with 25 out of 33 participants describing swatches as translucent, transparent, see-through or sheer. A total of 17 participants described the color as tan/beige, whereas 16 participants noted that the material surface had a wrinkly appearance. A total of 11 participants described the surface appearance as textured, some specifying that it had unique patterns and grooves. It is apparent that some participants perceived the surface appearance to be a unique feature of the material. To many participants, the material resembled a skin or hide (14) and had a worn/weathered look (10). Participants also thought that the material looked natural or organic (6).

Hearing attributes. The average number of attributes generated by participants with respect to the hearing sense was 1.6 per person, with a range of 0–5 attributes. In total, 54 hearing attributes were generated. Attributes that described the same ideas or characteristics were combined into categories. For example, paper-like sound, paper rubbing, book page-turning attributes were grouped into a paper-like sound category. A total of 19 distinct attributes were identified (4 high-frequency, 15 low-frequency). The low-frequency attributes related to properties of sound (e.g. crisp) and resemblance to other sounds (e.g. such as plastic).

High-frequency attributes included: quiet, leather-like sound, paper-like sound and scratchy when rubbed (Table 1). BC material was characterized as quiet when moved, bent or touched by participants (n = 9). However, when rubbed against itself, the material was characterized as producing certain sounds. Six participants noted that it made a scratchy or rough sound, and one stated: "The noise when you rub it with your fingers is very quiet, but it makes a louder scratching noise when folded and rubbed together." Others characterized this sound as leather-like (8) or paper-like (8).

Smell attributes. The average number of attributes generated for the sense of smell was 2.2 per participant, with a range of 1–5. In total, 73 smell attributes were generated. Grouping of the similar ones resulted in 32 distinct attributes (three high-frequency, 29 low-frequency). The high-frequency smell attributes included: unpleasant (10), vinegary (8) and old items/place smell (6). The low-frequency attributes related to properties of smell (e.g. strong/not strong, sour, sweet), presence or absence of smell (e.g. smells only up close, stays on hands, no smell) and resemblance to other smells (e.g. fruity, ammonia, flowers).

Touch attributes. The average number of touch attributes generated by the participants was 4.2 per person, with a range of 1–10. Participants generated 139 touch attributes in total. Combining the similar attributes (e.g. grouping flexible, pliable, bendable descriptors under flexible category), resulted in 37 distinct attributes (13 high-frequency, 24 low-frequency). The low-frequency attributes related to the material hand (e.g. smooth, tacky), performance (e.g. not elastic, flimsy) and resemblance to other products (e.g. fruit leather, vinyl).

High-frequency attributes included: textured, flexible, stiff, leather-like, rough, soft, rough and soft simultaneously, strong, durable, paper-like, thin, dry and plastic-like (Table 1). A total of 14 participants described the material as textured, wrinkly and having ridges or bumps. While eight

participants described it as rough, seven described it as soft. Interestingly, six other participants described the material as being at the same time rough and soft. Perhaps these participants perceived the material surface as textured/rough, but the overall material as pliable/soft. The contradictory responses could be due to the natural, slightly uneven distribution of the ridges and texture on the material surface.

Flexibility was another property receiving contradictory responses. The material was described as flexible by 11 participants, whereas 9 saw it as stiff, rigid and hard to bend. It is possible that more textured areas of the material were evaluated as stiff and smoother parts as flexible. Participants' associations of BC material with other materials may have also affected their evaluations, resulting in contradictory responses. For example, some participants described the material as leather-like (7) and others as paper-like (6) or plastic-like (5). Participants associating BC with plastic could have perceived it as more flexible compared to plastic. Several participants described BC material as durable (6), thin (6) and dry (5).

Part Two: rating the intensities and liking of bacterial cellulose material attributes

In Part Two of the sensory evaluation, participants rated the intensities of 25 predetermined sensory attributes describing BC on a scale of 0 (not at all) to 5 (extremely). They also rated how much they liked or disliked each attribute on a scale of 1 (dislike) to 3 (like) (Table 2). We identified the attributes with high (3.5 or higher) and low (1.5 or lower) intensity ratings, as well as those with high (2.3 or higher) and low (1.7 or lower) liking ratings. High scores are bold-faced and low scores are italicized in Table 2.

Sight attributes. The sensory category of sight contained attributes that received the highest intensity ratings, including wrinkly, leather-like appearance and translucent/see-through. The mean intensity rating for the wrinkly attribute was 4.48 (SD = 0.93), with a mean liking rating of 2.3 (SD = 0.80). While most participants thought the surface of material looked wrinkly, this was not considered a negative property. The translucent/see-through attribute had a mean intensity rating of 4.39 (SD = 0.65) and a mean liking rating of 1.79 (SD = 0.81), indicating that participants generally disliked the see-through nature of the material. Leather-like appearance had an intensity rating of 3.58 (SD = 1.21), and participants liked this attribute (M = 2.67, SD = 0.59).

Touch attributes. The average intensity ratings for rough/textured (M = 3.48, SD = 1.16) and dry (M = 3.55, SD = 1.52) attributes were the highest in the sensory category of touch (Table 2). The mean liking rating for the rough/textured attribute was 2.42 (SD = 0.78), indicating that many participants liked the unique texture of the material. The mean liking rating for the dry attribute was 2.33 (SD = 0.64), indicating that participants also liked this attribute. The heavy (M = 0.91, SD = 1.24) and sticky (M = 0.82, SD = 1.14) attributes had the lowest mean intensity ratings in this category, with many participants indicating that the material did not feel at all sticky or heavy. The mean rating for liking the heavy attribute was 2.58 (SD = 0.55), indicating that participants tended to like the weight of the material. The mean liking rating for the thick attribute was 2.48 (SD = 0.66), and the intensity rating was 1.79 (SD = 1.34), indicating that participants thought that the material was not very thick, and that they liked its thickness.

Smell attributes.

Attributes in the smell sensory category received the lowest intensity ratings (Table 2). Participants disagreed that the material had spicy or sweet smell, with mean intensity ratings for spicy-smelling and sweet-smelling attributes of 0.48 (SD = 1.02) and 0.91 (SD = 1.52), respectively. Similarly, the majority of participant thought the material did not have the smell of

overripe fruit (M = 1.39, SD = 1.74). The mean intensity rating for the pleasant-smelling attribute was 1.33 (SD = 1.59), showing that most participants did not think the material had a pleasant smell. This coincides with the findings from the Part One of the sensory evaluation, where many participants described the smell of the material as bad or unpleasant (Table 1).

Hearing attributes. All three hearing attributes had more neutral intensity and liking ratings (Table 2). The mean intensity rating was 2.73 (SD = 1.60) for the paper-like-sounding attribute and 3.00 (SD = 1.44) for the vinyl-like-sounding attribute, and with respect to both attributes, participants indicated that they neither liked nor disliked these material characteristics. The mean intensity rating was 2.03 (SD = 1.61) for the squeaky attribute, indicating that most participants did not agree that the material was squeaky.

Part Three: overall liking and acceptability of bacterial cellulose material

In Part Three of the sensory evaluation, participants rated their overall liking of the material and how acceptable the material was for clothing and accessories. An open-ended question also encouraged participants to provide additional comments about the material's characteristics and use. The mean rating for the overall liking of the material was 3.39 (SD = 0.83), indicating an overall neutral to somewhat positive attitude. While more participants liked rather than disliked the material, many participants were neutral. The mean rating for the acceptability of the material for clothing (e.g. vests, jackets) was 2.94 (SD = 1.30), indicating that many participants were neutral – neither liked, nor disliked the idea of the material used for clothing. In contrast, the mean score for the acceptability of the material for accessories (e.g. belts, bags, shoes) was 4.48 (SD = 0.76), with most participants agreeing that the material was very acceptable for the use in fashion accessories.

Table 3. Correlation Analysis (N = 33)

Variables	Overall liking of the material	Material acceptability for clothing	Material acceptability for accessories
Age			
Pearson Correlation	0.009	0.054	0.060
Sig. (two-tailed)	0.960	0.765	0.742
Year in college			
Pearson Correlation	-0.303	-0.034	0.062
Sig. (two-tailed)	0.086	0.853	0.730
Clothing purchased			
Pearson Correlation	0.206	0.168	-0.093
Sig. (two-tailed)	0.251	0.350	0.605
Money spent			
Pearson Correlation	0.033	-0.064	-0.229
Sig. (two-tailed)	0.855	0.721	0.199

Pearson correlation analysis was conducted using SPSS software to examine whether the ratings for the overall liking of the BC material, the acceptability of the material for clothing, and the acceptability for accessories were associated with age, year in college, number of clothing and accessory items purchased, and the amount of money spent on clothing and accessories (Table 3). No significant relationships were found. Age, year in college, number of clothing and accessories

purchased, and amount of money spent on clothing and accessories were not associated with the participants' liking of the BC material and their ratings of the material's acceptability for clothing or accessories. Basic demographic and shopping habit variables were tested. In the future, researchers may consider other variables such as awareness of sustainability issues in the apparel industry.

Open-ended responses. All 33 participants provided comments about the characteristics and the use of BC material. Comments related to material characteristics, its perceived performance, possible uses and suggested improvements.

BC material characteristics. The material was described as "too thin" and see-through or transparent, which, according to a participant, "might be seen as a negative, if it allowed the contents of the purse to be seen." This coincides with Part One and Part Two findings, as BC was described as see-through by most participants. Participants also noted that the material looked "distressed" and "raw." Its unique look, even though "not perfect" and "distressed" was seen as an advantage with potential for creating interesting, "avant-garde" products. The material was likened to skin, faux or old leather. Many participants noted that the material was a "great" and "natural" leather alternative, and some liked its naturalness, uniqueness, authenticity and earth-friendliness. The smell of the material was characterized as "off-putting," by many; however, few thought it "smells amazing" and that the smell was their "favorite thing about the material."

Perceived performance. Strength, flexibility and ability to "take a lot of wear and tear" were characteristics offered by participants to describe performance or functional aspects of the material. Similar attributes were also mentioned in Part One. Concerns about the durability of the material when wet were raised by several participants. A participant inquired: "Will it get soggy and weak?" While the perceived durability of the material was described both positively and negatively, in Part One, its performance under different environmental conditions was not mentioned. The material touching the skin, "rubbing and causing pain" was another concern for several participants. Caring for and cleaning the material was also a concern.

Suggested improvements. According to a few comments, the material could be improved by making it more opaque and thicker, and use of multiple layers was recommended to achieve this. This coincides with findings in Parts One and Two that showed that many participants did not like the transparency of the material. Another suggestion was to offer a greater variety of colors, specifically, dyeing the material "unnatural," "rich" or "just more" colors. Creasing of the material was also mentioned as a concern and fixing this was suggested to achieve higher quality. While the material was generally seen as "too stiff" for clothing items, "more structure and thickness" was recommended for use in fashion accessories such as bags.

Suggested uses. Participants suggested that BC material could be used for fashion accessories (e.g. bags, belts, shoes/sandals, jewelry and hair accessories), certain clothing categories (e.g. vests, motorcycle apparel, costume-making, accents/trims) and other consumer products (e.g. book covers, shopping bags, avant-garde fabrics). A participant noted that it could be used for "clothing and accessories that are usually made of leather." In general, participants felt that the material was not very suitable for clothing items, especially those worn close to the skin. The ratings of acceptability of BC for clothing and accessories also showed similar results.

Conclusions and implications

Sensory evaluation of textiles and apparel has traditionally focused on the senses of sight and touch (Balaji et al., 2011; Phillippe et al., 2003), thus leaving out the other human senses and the valuable

insight their analysis could provide. In this study, we developed and applied a new three-part method for HSE of textiles and apparel, considering the senses of touch, sight, smell and hearing. The HSE method was carefully documented, described and successfully applied in evaluating and gaining a broad understanding about BC, a novel sustainable material.

The results of the study have two important contributions for scientific knowledge and practice. First, the developed HSE method can be useful for academic research and industry practitioners, as discussed below. Second, the findings about consumers' characterization, perceptions and acceptability of BC material might be helpful for promoting further development and applications of this novel material and other similar materials, thus contributing to circularity of textiles and apparel. In addition, findings from this study can help to provide consumers with more accurate product information. This can help increase consumer satisfaction and adoption of novel and sustainable products, leading to more socially responsible behaviors.

Summary of results and directions for further bacterial cellulose development

In Part One of the HSE method, research participants describe a material or product being evaluated in their own words for the senses of sight, touch, hearing and smell. Attributes generated in Part One of this study were particularly valuable in gaining fundamental information about the BC material, as perceived and described by potential consumers, and identifying areas for improvements for further material development. Moskovitz (2008) justifiably stated that "attributes constitute the fundamental form of information by which the researcher taps into the mind of the consumer and […] understands how they perceive the products and […] why a particular product is acceptable or not acceptable" (p. 173).

In this study, 120 distinct attributes were identified describing BC, including 27 high-frequency attributes (mentioned by at least five participants) that revealed the most important sensory characteristics. BC was described as tan/beige color and see-through, and its surface was described as wrinkly or textured, with unique ridges and patterns. It was also described as organic-looking, leather-like and worn-looking (seen as both a positive [vintage] and a negative attribute). Some described the material as rough and stiff; others described it as soft and pliable. This could be due to the natural uneven textured surface of the material and its overall pliability. Material consistency and thickness could be improved to reduce its transparency, which was negatively viewed, and improve uniformity. However, the uniquely textured surface, a characteristic liked by many participants, should be retained. The smell was found to be another major product characteristics for improvement, as it was generally perceived as unpleasant. These findings, combined with Part Two and Three results, present holistic view of how potential consumers may characterize and perceive the material and products made of it and allow gauging consumer acceptance of such products.

In Part Two, participants rate the intensities of pre-determined product attributes, related to the four senses and indicate their liking of these attributes. If a suitable list of attributes does not already exist, it must be developed by an expert panel first. (Alternatively, attributes from Part One of the method could serve as basis for generating a suitable list or possibly combined with expert-generated attributes). For this study, a 25-attribute list was developed by an expert panel. The see-through attribute had one of the highest intensity ratings, while its liking scores showed that most

participants disliked this characteristic. Many participants thought the material had a leather-like appearance, and most participants liked this attribute. The wrinkly attribute had the highest intensity rating, with most participants also indicating their liking of this attribute. These results supported the findings in Part One. Unpleasant smell was also confirmed by this analysis, which also showed that see-through characteristic was perceived negatively and needed to be modified. Part Two of the evaluation was essential for determining the intensities of the product attributes experienced by participants and whether the attributes were perceived as positive or were liked.

Part Three of HSE measures participants' overall liking and perceived acceptability of a material or product for specific applications. In this study, participants rated how much they liked or disliked the BC material overall, as well as how acceptable the material was for clothing and accessories. While more participants liked than disliked the material, most participants were neutral, possibly due to their unfamiliarity with BC, a new material. Participants indicated that BC was not acceptable for general clothing, but it was very acceptable for accessories such as bags, belts and shoes. In open-ended responses, the material was described as see-through, skin- or leather-like, distressed, raw-looking and unique and the smell was "off-putting" to some. Concerns were raised about the material's durability when wet, its roughness as it touches the skin and needed care for products made of BC. Increasing its thickness and reducing transparency were suggested to improve the material. Offering a greater variety of colors and preventing the material from retaining crease lines were other suggestions. Participants also suggested that the BC could be used for fashion accessories and other consumer products such as book covers and shopping bags. Only certain clothing categories such as vests or motorcycle apparel were recommended for the material.

The three parts of the HSE method helped in gaining a broad understanding about the BC material, by adding additional layers of insightful information. HSE could be invaluable in understanding material and product characteristics and identifying areas for material improvement. As the textile and apparel industry searches for solutions to reduce its negative environmental impacts, new sustainable materials are being explored. As a result, BC has gained much interest in recent years (Kaminski et al., 2020; Provin et al., 2021), yet little is known about consumer perceptions of this novel material. HSE of BC from consumer perspective resulted in substantial new knowledge about this novel sustainable material. In-depth comprehensive understanding of how consumers view the material as well as which characteristics they like or dislike are critical for researchers and businesses who work on BC development and applications.

Applications of holistic sensory evaluation method

HSE of materials and apparel products is essential because of the increased importance of new materials (e.g. bio-based renewable materials) and rapid development of wearable technology and smart textiles and clothing (Lehmann et al., 2018; "Smart Textiles", 2017). The HSE method will be especially useful for evaluation of novel materials and products, which might evoke unusual sensory experiences due to properties acquired from certain production processes, fiber sources or other factors. The method allows for capturing and assessing the complete sensory characteristics of products. For example, as wearable technology and new materials gain more prominence, smells and sounds may also be experienced with plastics, wires, solar cells, or unconventional material used in apparel or other wearables. Capturing the full sensory profile of new products could also be useful in accurate descriptions of the products in virtual and online shopping environments, potentially improving consumers' shopping outcomes and reducing return rates due to unclear

product descriptions. Sensory evaluation could be of significant help to understand the characteristics of traditional and novel materials more broadly and fundamentally, based on consumer perspective and to improve product properties and marketing strategies (Meilgaard et al., 2007; Nagamatsu et al., 2020).

Researchers can apply the method to assess new materials and apparel products, including wearable technology, smart clothing, sustainable materials, as well as regular textiles and apparel products. The method allows in-depth understanding of various characteristics of materials and products based on the four senses of sight, smell, touch and sound. As discussed earlier, existing sensory evaluation studies in apparel and textiles have focused mainly on the senses of sight and touch (An et al., 2013; Balaji et al., 2011; Harpa et al., 2018). Comprehensive sensory assessment of consumer perceptions of products helps identify areas for improvement, avoid new product failure and provide language for marketing these products using consumer-generated descriptors. Businesses may find the method useful in evaluating new products and materials during product development stages.

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Table 1. High-frequency attributes[a] generated by participants describing sensory characteristics of BC material

Sight	*N*	Hearing	*N*	Smell	*N*	Touch	*N*
See-through (translucent, sheer, transparent)	25	Quiet (noiseless, no sound when bent or rubbed)	9	Unpleasant (bad)	10	Textured (surface lines, ridges, bumpy, wrinkly)	14
Tan color (beige, light-brown, yellowish)	17	Leather-like sound when rubbed	8	Vinegary	8	Flexible (pliable, bendable, foldable)	11
Wrinkly (crinkly)	16	Paper-like sound(paper rubbing, book page turning)	8	Old items (cloths, couch, library, antique shop)	6	Stiff (rigid, hard to bend, not flowy)	9
Skin-like (looks like skin, hide, skin graft)	14	Scratchy noise when rubbed (rough sound when rubbed against itself/with hands)	6			Rough	8
Textured (cracks, grooves, unique surface details, uneven)	11					Leather-like	7
Worn-looking (rustic, distressed, weathered, antique-like, old-looking)	10					Soft	7
Natural (organic)	6					Strong (tough)	7
						Durable	6
						Paper-like	6
						Rough and smooth/soft at the same time	6
						Thin	6
						Dry	5
						Plastic-like	5
Total attributes generated	99		31		24		97
Total distinct attributes	7		4		3		13

Notes: N = attribute frequency[a], Attributes with frequencies of five and above