ABSTRACT

QIU, ZIWEN. Exploring Clothing Movement in 3D Apparel Motion Simulation. (Under the direction of Dr. Anne Porterfield and Dr. Kavita Mathur).

This research explores the intersection of visual perception and comfort in 3D apparel motion simulation, focusing on women's activewear in the U.S. market. The research aims to establish a foundational understanding of how consumers perceive clothing movement in simulated 3D activewear, linking these perceptions to virtual fabric properties. Utilizing a mixed-method approach that combines focus group discussions and a MaxDiff Conjoint Approach survey, the study identifies key descriptors of visual perception: flexibility and supportability. These descriptors are crucial in understanding the interplay between clothing movement and visual comfort.

The findings reveal that flexibility and supportability significantly influence visual comfort perception in different ways. The study demonstrates that the descriptors, especially in the context of 3D jumpsuit simulation motion video, correlate with the comfort levels perceived by viewers. Regression analysis further illustrates how virtual fabric parameters, and their interactions affect the visual perception of clothing movement, flexibility, supportability, and comfort. Additionally, the study introduces the concept of virtual fabric comfort clusters, categorizing fabrics into distinct comfort levels based on visual perception. This classification provides a novel perspective in the field of 3D apparel simulation. The research underscores the pivotal role of virtual fabric properties in determining the visual comfort and movement of simulated apparel.

In conclusion, this thesis offers significant contributions to the understanding of visual-tactile perceptions in 3D apparel motion simulations. It presents a new framework for evaluating and enhancing the quality of 3D apparel design and development, providing valuable insights for product designers, developers, and researchers in the field.

Exploring Clothing Movement in 3D Apparel Motion Simulation

by
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DEDICATION

To unexpected experiences and redirected paths.
To friends and family who've become my everything.

BIOGRAPHY

Ziwen “Jackqee” Qiu, born on April 11, 1995, in Shanghai, China, started her academic journey at Donghua University, formerly known as “China Textile University,” in 2013, pursuing a degree in Fashion Design and Engineering. She concluded her undergraduate studies in the summer of 2017, earning a Bachelor’s Degree in Engineering. In her senior year, 2016, Qiu seized the opportunity to further her education through the “3+X” program at Wilson College of Textile, North Carolina State University, specializing in Textile and Apparel, Technology and Management. This led to her obtaining a Master’s Degree in Textiles in the winter of 2017, after a rigorous one-and-a-half-year study.

Following her graduation, Qiu ventured to Hong Kong, where she started her professional journey as a technical designer focusing on bra development with Clover Group International Limited. In 2019, she returned to Wilson College of Textile to pursue a Ph.D. in Textile Technology Management, dedicating herself to full-time studies. Concurrently, since 2021, she has taught the FTM315 apparel product design course at the college. Furthermore, starting in 2022, Qiu has been involved as a digital apparel and sizing/fitting intern with Humanetics Digital of North America, formerly known as “Human Solutions of North America.” Adding to her impressive portfolio, from the onset of 2024, she has taken on the role of a research assistant, focusing on the sizing/fitting, and product development of female firefighter clothing.

Each of these roles underscores her profound commitment to the apparel industry, reflecting her ambition to make significant contributions to the field post-Ph.D. graduation.

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1. INTRODUCTION

1.1 Research Background and Problem Status Quo

In a purely visual online shopping environment, the content that a product's descriptive text and image bring to the consumer is interactive, creating a relational sense of the fashion product that is important to the consumer's shopping experience (Kawaf & Tagg, 2012; Wu et al., 2013; Cheung & Vazquez, 2015). For instance, some women's activewear companies use words that are full of movement sense, such as "flow" (Victoria's Secret, 2024), "like a cloud" (Lululemon, 2024), or "made to move/play" (Aerie, 2024), or include more functional descriptions in their product features to link physical properties of fabric to wearing comfort (Victoria's Secret, 2024). Usually, the product display to show clothing movement is accompanied with video showing the dynamic wearing state, so that consumers are preconditioned to have an impression that the apparel product they shop for has movement to perform as described. Even though appearance is the primary vehicle of product expression in the online environment, and it has a stronger impact than text description (Racat & Capelli, 2020), there is still a lack of theory and practice to understand visual perception as a tool for assessing apparel product features.

In recent years, the adoption of digitalization in the fashion industry has caused 3D simulation technology to be increasingly implemented for communicating apparel products' appearance (Gonzalez, 2022). By using 3D simulation technology, 3D apparel designers create dynamic visualizations for producible apparel products to predict and communicate the wearing effect of designed apparel. 3D simulation technology allows apparel practitioners to display their clothing designs in a virtual environment, complete with realistic movements. This advancement reduces the reliance on producing multiple physical prototypes or samples for demonstrations and fittings (Kabakibi & Eriksson, 2023). Furthermore, 3D simulation technology has transformed the retail experience, easing the shift from prototyping to the final retailing stage. This change is largely due to the adoption of 3D simulation displays that efficiently reflect consumer preferences in design (Dal Forno et al., 2023). As a result, the appearance of apparel products in simulations has become more functional and integrated. 3D simulation technology serves not just designers and developers in conveying real product attributes but also enhances consumer engagement by providing a more immersive and realistic viewing experience. Despite these advancements, a limitation remains: 3D apparel designers are still unable to receive immediate feedback from viewers about whether the simulated clothing materials convey the same tactile impression as intended in the design. This is a hindrance to improving the overall quality and authenticity of 3D apparel designs, and a limitation to further applications of 3D simulation technology in apparel industries. A standard to stipulate the conditions, procedures, and measurements for testing the visual perception of clothing movement in simulated apparel display is necessary (Sun & Zhao, 2018). Given that the existing experimental results are presently insufficient to establish such a standard, this research aims to contribute to that foundational body of knowledge. The research conducted experiments to explore how viewers perceive clothing movement within 3D apparel simulations, focusing particularly on the dynamics of apparel in motion. It also investigated the impact of virtual fabric simulation parameters on the viewer's perception of clothing movement, with the objective of refining and augmenting the realism in these virtual presentations. This research is fundamental to the apparel practitioners and researchers who use and develop 3D simulation technology, helping them to simulate apparel in motion that better match viewers' perception, and on this basis to develop the evaluating standard for visual assessment of clothing movement in simulated apparel display in future. The following subsections present more background of clothing movement and 3D apparel motion simulation to demonstrate how this exploratory study lays the foundation for filling the main gap.

1.1.1 Clothing Movement in Apparel Presentation

In currently accessible literature, Griffiths and Kulke (2002) conducted the first assessment of how viewers perceive clothing movement using videos of apparel as visual stimuli. Their study was motivated by the increasing use of freedom of movement as an important clothing feature, so the researchers explored the quantification of clothing movement and its correlation to technical measures of fabric. In their experiment, they filmed a knee-length A-line dress and a pair of wide-leg trousers from multiple angles worn in walking situations as the motion display. Visual assessment was conducted by asking the participants to score nine key attributes describing the appearance of movement (flowing, folds, cling, swing, bounce, drape, shape retention, heavyweight and thickness). Additionally, a panel of participants evaluated three fabric tactile attributes (smoothness, softness and stiffness) on scales from 0-100 through real touch (Griffiths & Kulke, 2002, p.254). The data from both visual and tactile evaluation were tested for correlation with objectively measured fabric mechanical properties. Their study identified the language to comprehensively interpret the visually perceived clothing movement as a set of nine attributes. A perceptual map of movement was also proposed to position the fabric, which they tested based on two dimensions — lightweight-to-heavyweight and flowing-to-stiff — to visualize the relationship between the fabric type and the total movement of the dress they made. Furthermore, Griffiths and Kulke concluded that the drape coefficient was a potential predictor for movement perception. This conclusion characterized clothing movement as related to "dynamic drape", but they found the single predictor could not reproduce the full picture of "movement fingerprint" as sufficiently as the sensory descriptive evaluation system (Griffiths & Kulke, 2002, p.254).

Other previous studies have referred to the visual assessment of clothing movement when reviewing clothing comfort (Choudhury et al., 2011; Kamalha et al., 2013) but there is a lack of interpretation regarding the relationship between clothing movement and clothing comfort in existing research. Additionally, while earlier studies have developed methodologies for the visual assessment of clothing movement in apparel with dynamic flow, such as flare skirts, these studies faced limitations due to a narrow range of apparel types and motion variety (Xue et al., 2016). Therefore, diversifying the combinations of visual stimuli used in experiments has represented another crucial focus of this research, aiming to provide a more comprehensive understanding.

1.1.2 3D Apparel Motion Simulation in Apparel Product Display

3D apparel simulation, now a widespread tool in the apparel industry, has been implemented to display the apparel wearing state, which orients viewers' emotions and inferences about the apparel product (Bug & Helwig, 2020). When the 3D apparel simulation features multiviews and is of good quality, it can be recognized as an accurate and visually engaging virtual representative of an apparel product (Bug & Helwig, 2020). 3D simulation technology delivers "the functionality of a product by incorporating visual, tactile, and behavioral affordances" (Li et al., 2003, p.406, as cited in Bug & Helwig, 2020). Particularly for products that require touch, such as apparel, the motion shown in simulation videos could help viewers to estimate the tactile sensation of wearing the product (Kühn et al., 2020).

Current apparel simulating tools including 3D Computer-Aided-Design (CAD) systems facilitate these simulations, which support the incorporation of various external files, such as fabrics, avatars, and patterns. (Jevšnik et al., 2014; Jhanji, 2018). This capability enables designers to create animated, digital replicas of garments, closely approximating the actual products in visualizing their main shape and structure, as demonstrated by several research cases (Zhang et al., 2021; Shim et al., 2022). Despite this, 3D simulation still falls short of being a complete representation of the real garment. This shortfall is primarily due to the inherent limitations in how 3D simulation technology models fabric. Fabric in apparel simulations is typically treated as a particle-based model, which is a simplification of the micro-geometrical structures of real fabrics(Jevšnik et al., 2014). This simplification, though boosting the efficiency of the simulation process, leads to discrepancies between the virtual garment's movement and the actual behavior of the real-world fabric. For instance, in a study by Zhang et al. (2021), loose-fitting pants worn by a walking subject were captured using a 4D scanner. The scanned data was then compared to the 3D simulated replica of those pants. The pants simulation did not reproduce the real movement accurately, and deviations were more significant for knit fabrics than woven ones.

Nevertheless, despite such challenges in replicating real-world movements, the properties of virtual fabrics in 3D CAD systems are adjustable. 3D apparel designers have the flexibility to modify various parameters related to visual and modeling design to enhance the virtual garment's realism. Mastering this adaptability in altering virtual fabric properties is a crucial skill for 3D apparel designers, signifying a key component of fabric digitization and emphasizing the necessity for expertise in 3D design manipulation (Casciani et al., 2022). Thus, in this context, virtual apparel is a combination of real and virtual components, where careful adjustment of parameters by designers plays a pivotal role in enhancing the virtual garment's fidelity to its real-life counterpart. However, there is a lack of research examining into how viewers specifically interpret the movement of clothing within these dynamic apparel simulations, to support the evolving practices of presenting and communicating virtual garments and fabrics in dynamic form. Detailed studies in this area could reveal key factors that influence the perceived realism and effectiveness of virtual garments, guiding improvements in 3D design manipulation to more accurately mimic the nuances of real fabric behavior, thereby improving the overall quality of these digital representations.

The current research landscape also indicates that there is minimal focus on exploring the parametric nature of virtual fabrics through the lens of individuals with expertise and background knowledge in actual fabrics' evaluation. Investigating visual-tactile perception of virtual fabric is vital, as it provides professionals in the textile and apparel industry with an intuitive understanding of virtual fabric parameters, fostering their ability to make informed adjustments that resonate with the tactile reality and craftsmanship of physical textile and apparel production (Gangoda et al., 2023). 3D apparel motion simulation remains a promising tool for representing clothing visually, with vast potential for future research.

1.2 Research Gap

Upon delving into the research background and problem status quo, a significant gap is evident in the current research on 3D apparel motion simulation as a tool for apparel display. Specifically, there is an unexplored area regarding what sense of clothing movement is conveyed to the potential audience, primarily fabric and clothing consumers, through these simulated displays. While 3D CAD systems for apparel are designed to simulate the movement of garments' digital replicas, there is a lack of research that examines the visual experience of viewing clothing in motion to ascertain the validity and effectiveness of such digital replicas. Little is known about how adjusting the virtual properties of the digital replicas can affect viewers' perceptions of the garments. Thus, investigating the objectivity of clothing movement perception becomes essential. Such an investigation would not only bring implications for both users and developers of simulation technology but also make the simulated clothing more visually expressive to stimulate viewers' tactile perception. Integral to advancing this field is the development and refinement of methods to effectively utilize and assess dynamically visualized apparel. This advancement could ensure a more robust and practical application of dynamic apparel visualization in real-world scenarios.

1.3 Research Aim and Questions

This study aimed to obtain a general idea of viewers' visual perceptual changes as simulation parameters are changed to help 3D apparel accurately convey clothing movement features through 3D apparel motion. While relevant to all clothing types, this study focused on women's activewear in the U.S. market, to figure out how U.S. consumers of women's activewear perceive clothing movement when watching simulated 3D activewear in motion, and the relevance of their perception to aspects of virtual fabric properties. The study aimed to comprehensively elucidate the specific visual perceptions associated with clothing movement and empirically link these perceptions to influential virtual fabric parameters in the final conclusions. A mixed-methods approach comprising a focus group study and a survey using Maxdiff Conjoint approach was utilized to accomplish the aim of the study.

The study was guided by three principal questions, detailed as follows:

- RQ1: What aspects of virtual fabric properties influence clothing movement perception? The existing research has yet to investigate how virtual fabric parameters influence observable visual features of simulated clothing, distinct from their real fabric counterparts, and understanding the rules' governing simulation is fundamental to studying the visual perception of clothing movement in the context of virtual clothing. To this end, the current study established suitable criteria for narrowing down the adjustable variables that present virtual fabric properties in apparel simulation software. The suitability of the criteria was verified through reviewing previous research cases and conducting a simulation test in the current study.
- RQ2: What descriptors show how consumers evaluate clothing movement in the context of 3D apparel motion simulation?

In this context, a descriptor is a consumer-based “key significant sensory attribute” to be extracted by using Descriptive Sensory Analysis (Kemp et al., 2018, p.310). To address this question, the study adopted a language development method outlined by Kemp et al. (2018) to elicit descriptive terminology, enhancing the precision of literal descriptors for measuring sensory responses. Specifically, this question aimed to extract descriptive words that captured consumer’s perceptions of simulated clothing dynamics as visual stimuli. In other words, it aimed to identify the language expressions used by consumers to describe the significant virtual clothing dynamic behaviors that convey a sense of movement.

- RQ3: What are the virtual fabric properties that are most impactful to visual perception of clothing movement?

The existing studies have examined and indicated the relevance between fabric physical properties and the perception towards fabric dynamic appearance in various clothing visualizations (Xue et al., 2016; Bi et al., 2019; Jimba et al., 2020). Similarly, this study aimed to identify the virtual fabric properties that may serve as objective factors contributing to the perception of clothing movement based on empirical evidence.

1.4 Definition of Key Terms

Table 1

Definition of Key Terms

Terms	Definition	Example
Clothing movement	Visually perceived apparel mobility, functionality, and comfort (Griffiths & Kulke, 2002, p.230)	(Evaluated by fabric and movement descriptors)
Fabric descriptors	Material associated attributes describing fabric hand and appearance properties visually perceived from 3D apparel motion simulation (Griffiths & Kulke, 2002, p.254)	Shape retention, heavyweight, thickness

Table 1 (continued)

Definition of Key Terms

Terms	Definition	Example
Movement descriptors	Movement associated attributes describing the dynamic behavior of 3D simulated apparel in motion (Griffiths & Kulke, 2002, p.254)	Flowing, folds, cling, swing, bounce, drape

1.5 Research Significance

This research took apparel consumers' overall visual perception as an entry point to study clothing visual-tactile properties related to 3D apparel motion simulation. The findings of this study could serve as a foundation for establishing technical measures for visually perceived clothing movement through 3D apparel motion simulations based on apparel customers' perception. This would aid 3D apparel CAD users, especially product designers and developers, in evaluating and optimizing the features of clothing movement in their designs. Moreover, this research will bridge the gap between fabric characteristics and virtual simulation technology, thereby paving the way for further research on the quantification of visual-tactile perception. Overall, the outcomes of this research will contribute to enhancing the quality of 3D apparel design and developments and provide new insights into understanding the links between visual perceptions, virtual fabric properties and virtual apparel movement.

1.6 Thesis Outline

The paper is organized in the following manner to illustrate the need for this research and outline how it was carried out. Chapter 2 is the literature review. The review starts with an in-depth interpretation of clothing movement, extended to the status quo of exploratory and quantitative research on fabric sensorial comfort, since clothing movement falls within the family of sensorial comfort (Kamalha et al., 2013). The review also covers the field of 3D clothing simulation. Emphasis is placed on illustrating how real elements of apparel (e.g., fabrics, garments, etc.) have been digitized to be constructed virtually. The methods of the designed research were also reviewed to include the measuring tools and the reasons for choosing these methods. Chapter 3 details a research path with methodology and explains the experimental procedures. Chapter 4 presents the findings and analysis. Chapter 5 discusses these findings in relation to the literature reviewed. This chapter offers a comprehensive summary of the key findings, reflecting on their broader implications. It also delves into the significance of the research’s outcomes, discussed its limitations, and proposes areas for future research.

2. LITERATURE REVIEW

A review of completed and on-going research has been conducted to identify current knowledge or methodologies for exploring the objectivity of clothing movement in the context of 3D apparel motion simulation. The review of literature contains four aspects. The details are as follows:

- Section 2.1 introduces the definition of clothing movement and its positioning in the field of sensorial comfort. This section also sorts out the influential factors of physical clothing that are potentially related to the perception of clothing movement.
- Section 2.2 explains that visual and tactile comfort are both sensorial comfort, thereby creating a link to tactile clothing comfort research that enlightens the studies on visual perception of clothing comfort. This section also reviews the studies addressing how clothing as visual stimuli influence visual perception of clothing comfort.
- Section 2.3 explains how 3D simulation technology enables construction of virtual clothing samples and displayed clothing products by taking real clothing components as input. This section sums up the technical correspondence between the visual features of simulated apparel and their real components.
- Section 2.4 describes the significance of the chosen experimental methodologies — the Focus Group Study and the MaxDiff Conjoint Approach — in relation to the aim of this study, with the evaluation tools detailed.

2.1 Clothing Movement: a Type of Sensorial Comfort Perceived by Vision

In the first study using apparel videos to explore visual assessment of clothing movement, Griffiths and Kulke (2002) interpreted clothing movement as “apparels’ qualities of mobility, functionality and comfort” (p.230). They believed that the clothing movement was becoming an important clothing feature with the invention of engineered stretchy fabric (e.g., Lycra®), and further with people’s increasing consciousness that clothing can bring moving convenience conforming to their lifestyles and activities. As introduced in the research background, Griffiths and Kulke (2002) aimed for the quantification and correlation of clothing movement to fabric technical measures. They found nine descriptors to evaluate total clothing movement that were classified to two groups, namely “attributes describing movement (flowing, folds, cling, swing, bounce, drape), and material associated attributes (shape retention, heavyweight and thickness)” (Griffiths & Kulke, 2002, p.254). A perceptual map of movement was proposed to visualize the relationship between the fabric type and the total movement of the dresses used in their study, related to two fabric attributes, lightweight-heavyweight and flowing-stiff. They also proposed a potential predictor for movement perception, drape coefficient, to suggest the commonality of vision and touch in clothing movement perception. However, there remain unanswered questions related to this topic. First, their pilot study is undisclosed, so the theoretical basis and pre-validation of the methodology for this research is unknown. Second, whether these descriptors are independent has not been studied. Although the researchers highlighted the importance of each descriptor for evaluating movement, they did not clarify if these descriptors could be further simplified. It remains unclear whether a hierarchical relationship exists between the attributes describing movement and the material associated attributes they proposed. Third, only loose-fit garments have been tested, which cannot give full play to the characteristics of stretchy fabric compared to fitted garments. Therefore, the descriptor they obtained may not be applicable to fitted wear, since clothing dynamics behaving in the air gap between body and clothing can hardly be observed by vision in this case. Building on the insights gained from this pioneering research, further studies should examine a broader range of clothing factors, aiming to identify key visual features that capture viewers’ attention. Understanding the interplay of these clothing elements is crucial, as different elements of clothing not only individually but also collectively contribute to the overall visual stimulus, thereby influencing the perception of clothing movement. This comprehensive approach aligns with the broader understanding of sensory perception in apparel (Bishop, 2008).

Kamalha et al. (2013) reviewed and summarized Griffiths and Kulke’s research into the category of “a sensorial aspect of clothing comfort” perceived by vision (Kamalha et al., 2013, p.428). They pointed out that a high relevance of clothing’s visual attributes to fabric mechanical properties emerged in both in-person and digital media environments. They also reiterated the role of fabric drape in correlating visual and tactile sensations. Issa et al. (2021) developed a cloth drape meter for measuring fabric drape in both static and dynamic states. They replaced the conventional tester settings (disks and cloth pieces) with rotatable 3D printed female mannequins and circle skirt samples, to bring the measuring process closer to the motion of the fabric being worn. Their experimental results showed that the dynamic drape was consistent with the static drape, associated with fabric weight, bending properties and extensibility. Combining the above studies mentioned, it can be estimated that fabric weight and shape retention may have a predictive relationship with the perception of clothing movement (Kamalha et al., 2013; Issa et al., 2021). However, the clothing features such as clothing design, fit and openings influencing visual comfort perception have not been mentioned in the sensorial comfort review by Kamalha et al. (2013), even though their positioning of clothing movement is helpful to understand this concept in the division of comfort system. Complementing this, the review by Choudhury et al. (2011) elucidated the perception of clothing movement from the perspective of the clothing-body system. They considered body movement comfort as "the ability of a textile to allow freedom of movement, reduced burden, and body shaping, as required" (Choudhury et al., 2011, p.22). They stated that four objective clothing factors (weight, ease of movement, stretch and ventilation) were related to comfort maintenance for body movements (Denton, 1970 as cited in Choudhury et al., 2011, p.25). These factors can be divided into two categories: textile factors (weight and stretch), which refer to the physical characteristics differentiating materials, and "wearability factors", among which ease of movement and ventilation are key. Weight and stretch are also important attributes characterizing fabric drape as mentioned in the previous paragraph (Raccuglia et al., 2018, p.33). Contrasting with the tactile nature of weight and stretch, ease of movement pertains to the garment's design and its capability to allow unrestricted motion. Garment ease, or dynamic ease allowance, refers to the additional space designed into clothing that permits the wearer to move freely, ensuring that clothing supports the body's movements, and enhancing the wearer's comfort (Huck et al., 1997; Ng et al., 2008.) Visual assessment of garment ease could give particular attention to key anatomical landmarks — the bust, waist, and hips — which are pivotal in visually determining clothing mobility. Illustrating this, research by Ng et al. (2008) serves as an example where dynamic ease allowance of functional wear was analyzed by the space between the garment and the body at these key cross-sections, thereby supporting the significance of these points in visual evaluations of garment movement. Furthermore, by analyzing different pattern-making methods for a woven-fabric-made dress, Lage and Ancutiene (2017) found that the general range of ease allowance for achieving fit and semi-fit is [3cm, 10cm] at bust and hip girths, and [2cm, 8cm] at waist girth, but quantifying ease solely from a perspective of visual perception remains an open area for investigation (Gill, 2011).

When it comes to tight-fit apparel, negative ease is necessary to provide appropriate skin pressure for wearing comfort —a concept complementing traditional garment ease (Yu, 2011). In such a context, garment pressure is the more relevant factor for evaluating and optimizing movement comfort (Liu et al., 2016). Garment pressure in a standard standing posture has been suggested as a benchmark to evaluate the state of pressure comfort in other varied static postures (Liu et al., 2021). Therefore, the differentiation of garment ease and garment pressure is important for understanding movement comfort perception across a full range of garment fits.

This section reiterates a critical insight from existing research: clothing movement is theoretically inferred to be a type of sensorial comfort that can be perceived visually. The visual interplay between dynamic garments and their wearers forms a stimulus that triggers these visual comfort responses in both in-person and digital media settings. Although the precise impact of this visual stimulus on the perception of clothing movement needs further research to elucidate, insights from tactile comfort research imply that variations of textile and clothing factors, such as fabric weight, stretch, bending properties, and garment ease/pressure, could influence visual descriptors of clothing appearance, like fabric drape, thereby potentially affecting the visual perception of clothing movement.

2.2 Exploration and Quantification of Sensorial Comfort

The previous section has delineated that clothing movement is a type of sensorial comfort that can be perceived visually (Kamalha et al., 2013). Kamalha et al. (2013) also suggested that sensorial comfort in clothing is a multi-sensory synthesis, including the sensation perceived by touching (e.g., tactile, thermal, moisture, pressure), hearing (acoustic), looking (visual or aesthetic), and smelling (olfactory). Neuroscience supports the view that comfort is perceived as a holistic feeling, even though it can be initiated by distinct sensory inputs (Wismeijer et al., 2012). This is exemplified in the way vision and touch can both trigger cognitive processes, including memory recall, leading to a synesthetic sensation (Winter, 2019). This synthesis indicates that the brain helps rationalize what we see or touch, to complement the overall impression in a way that is uniform across the two senses. In the context of this research, understanding this neural mechanism can enrich our interpretation of how visual perceptions of comfort in clothing are formed. Generalizing the reviewing scope of the current research to encompass other aspects of clothing sensorial comfort, beyond just visual, could provide a more comprehensive understanding of how solely visual perceptions of comfort are formed and rationalized.

The following subsections present the studies on clothing tactile comfort, meaning the sensations like smoothness and softness perceived through touch (Kamalha et al., 2013). This focus was informed by the fact that tactile comfort has been mostly studied in the field of clothing comfort perception towards real fabrics, yielding relatively sound systems for practical evaluation and measurements of clothing comfort from theory. Additionally, the end use of textiles and apparel usually requires skin contact and interactions, so tactile sensations form a foundational cognitive reference that informs perceptions across other sensory channels (Choudhury et al., 2011). Building on this, the following subsections elicited the influence of clothing fabric as visual stimuli on comfort perception by reviewing additional studies.

2.2.1 Fabric Hand System: Tactile Comfort and Its Evaluation

In studies concerning tactile clothing comfort, the concept of fabric hand has been extensively employed for assessing comfort perception. This area of study has offered many methodologies that hold relevance and provide guidance for investigations into visual comfort in apparel. The following subsections detail these important findings to draw connections to their applicability in the context of visual comfort research.

2.2.1.1 Fabric Hand and Hand Elements. The concept of “fabric hand”, also known as fabric touch or fabric handle, has been defined as “the tactile sensations or impressions which arise when fabrics are touched, squeezed, rubbed or otherwise handled” (AATCC, 2016, p.422). Fabric hand serves as a subjective indicator that captures the diverse fabric quality and performance discerned through touch (Choudhury et al., 2011). There are constituent elements of fabric hand identified as the attributes or impressions related to fabrics' characteristic sensation of touch (AATCC, 2016).The AATCC (2016) delineates fabric hand into elements that reflect the sensory attributes associated with the characteristic feel of a fabric, originally categorizing the hand elements to four fabric physical attributes in 1990, namely compression, bending, shearing and surface. ASTM Standard D123-19 expanded upon these elements, classifying the elements into eight attributes, namely flexibility, compressibility, extensibility, resilience, density, surface contour, surface friction and thermal character (Hatch, 1993; Behery, 2005a). A few recent studies adopted a more refined classification that aligns these attributes with corresponding human sensory responses, streamlining them into four attributes, namely thermal, surface, bending, and compression (Liao et al, 2014).

In the field of clothing fabrics, the fabric hand elements are the characteristic hand feel of the fabric in certain apparel usage (Cardello et al., 2003; Cheng et al., 2020; Kim et al., 2020). A pivotal advancement in the industrial standardization of fabric hand elements was by Kawabata (2005), who proposed the concept of fabric hand on the premise that the assessment of the fabric hand is related to the mechanical properties of fabric and is influenced by the intended end-use of the fabric. His proposition was supported by his expert committee — and they successfully narrowed down the key hand elements for conducting panel tests to evaluate the quality of men's suiting fabric. The results of their study have been integrated into the operational standards of numerous Japanese corporations (Kawabata, 2005).

2.2.1.2 Descriptive Sensory Analysis. Descriptive Sensory Analysis is a technique that has been frequently used in fabric hand evaluation to explore descriptors under physical attributes (Gacula, J., 2008). In the United States, the AATCC (2016) and ASTM (2021) provided standard guidelines to guide the implementation of specific descriptive sensory evaluations. The Union of Japanese Scientists and Engineers mirrored this approach with standards set by pertinent authoritative bodies to inform material sensory evaluation protocols (Union of Japanese Scientists and Engineers, 1999 as cited in Kitaguchi et al., 2015, Isami et al., 2021). Common to these standards is the use of antonymic descriptors to present the hand feel(e.g., thin and thick, stiff and pliable), which have become a staple in fabric hand research.

In terms of methodological strictness, the way to extract the descriptors varies across studies. Some researchers opted for a straightforward way, selecting the words directly from the standards (Luible et al., 2008; Liao et al., 2016; Xue et al., 2016; Tadesse et al., 2019). While efficient, this strategy faces the challenge that the standard terms are very broad, designed to cover a wide range of contexts for universal applicability. Therefore, precision in the interpretation of these terms becomes critical. Training participants to comprehend the specific nuances of each descriptor, such as the type of fabric force responses, is an important prerequisite for experimental validity. Compared with selecting descriptors, a more meticulous method involves the pre-validation of participants' understanding of the terminology. For example, Watanabe and Horiuchi (2021) conducted an evaluation word extraction test in their research on modeling the common impressions of perceptual visual quality of leather. Their method involved an initial phase where participants wrote down adjectives that resonated with their impressions of leather. This step was followed by an appropriateness test, a subjective pre-screening designed to filter and refine the vocabulary pool. After that, they conducted a semantic distance test to ensure that each descriptor is a distinct entity rather than a compound word. This thorough process led to the creation of a set of unique descriptors specifically designed for their study, highlighting the importance of careful verification when creating a reliable set of terms for evaluation.

In research where participants solely rely on visual sensations, it is common for participants to describe what they perceive in tactile terms (Winter, 2019). This suggests that even when the task requires only visual judgment, the language of touch permeates descriptive vocabularies. This indicates an interlink between visual reception and tactile perception, and our language reflects this interplay. Visual adjectives dominate sensory communication, since vision is the most versatile and protective sense (Williams, 1976, as cited in Winter, 2019, p.137). The instinct to capture visual features allows humans to determine danger before touching (for example, blue-black food indicates that it potentially rots or deteriorates) to avoid possible threats from contact (Xiao et al., 2016). Conversely, the sense of touch, while more direct, is also the most analyzable with its intensities easily scaled and detailed, which lends itself to a structured and nuanced description (Popova, 2005, as cited in Winter, 2019, p.150). Therefore, the intensity of touch is the most measurable compared to other senses, so that the description from the tactile perspective can usually be subdivided to different dimensions and graded on an interval scale. Despite this, subjective evaluations of fabric hand often exclude visual input through blindfolding to ensure a purely tactile responses (Yang et al., 2014; Spence, 2020). This methodology indicates that while a singular sense can be studied in isolation, the complete experience of comfort is a synthesis of multiple sensory inputs. Even though the established tactile evaluation systems are thorough enough to be reproducible, the pattern of vision-only comfort perception remains underexplored and not fully understood. This indicates a gap in research that needs to be addressed for a comprehensive understanding of comfort perception through vision alone.

2.2.1.3 Objectivity and Objective Measuring of Tactile Comfort. As explained above, the current understanding of tactile comfort in clothing has often been at the forefront of sensory comfort research. Going back to the exploratory history of measuring tactile comfort is helpful for the research on sensorial comfort perception acquired from other senses. Historically, fabric tactile feeling was considered too subjective and elusive to quantify but advancements in neuroscience paved the way for objective measures, where fabric touch sensation are understood as the signal generated from the physical contact with fabric (Liao et al., 2014). This interaction between touch and fabric is now quantifiable through the value of force required to cause the dimensional deformation of the fabric, which transforms the subjective into objective (Hatch, 1993). Recent research applied optical sensors to detect the force from the camera-captured deformation, representing a breakthrough (Yuan et al, 2017; Sferrazza & Andrea, 2019). These recent approaches indicated that the attributes of tactile comfort feelings related to the deformations of fabric, such as compression, bending, and shearing, are now being correlated with visible properties, suggesting that objective modeling of tactile comfort is possible.

EL Mogahzy-Kilinc hand method is one of the earliest instrumental testing methods to directly achieve both fabric hand integration and individual hand attributes, as it interprets fabric hand by simulating physical fabric movements and using electronic sensors to collect force data (Behery, 2005b).

The operation of the physical simulation is pulling the circular fabric sample through the funnel so that a force-time profile is generated during pulling. This profile is termed as “hand profile”, divided into four zones under the curve to interpret the drape behavior, a combination of stretching, compression, shear, bending stiffness and fabric inter-fold friction, folding flexibility, and surface roughness respectively. The sum of the four zones is called objective total hand. Its main application is evaluating the same type of fabric under different treatments.

The simulatability and interpretability of the El Mogahzy-Kilinc method provide a precedent for similar instruments in the future. Continuing advancements in instrumentation are yielding more nuanced and precise evaluations, building upon the foundations laid by such early methods. (Hu et al, 2006; Pan, 2006; Liao et al., 2016). This progression is complemented by more experimental evidence that shows the reasonableness of studying fabric physical properties as an entry point to build the relationship between physical worlds and the tactile comfort sensations (Kamalha et al., 2013). Demonstrating this relationship, research in military clothing has predicted comfort based on fabric physical properties (Cardello et al, 2003; Sztandera et al., 2013). Broader applications have seen artificial neural networks successfully linking tactile assessment data to physical characteristics (David and Ding, 2005; Tadesse et al., 2019). David and Ding (2005) built a stiffness prediction model by using artificial neural networks to connect tactile assessment data with fabric physical properties, taking 75 light-to-medium-weight woven fabrics as samples. Tadesse et al. (2019) also used artificial neural networks and adaptive network-based fuzzy inference systems to model the prediction of perceived Total Hand Value of functional fabrics by inputting fabric instrumental measurements. The two examples of predictive model development represent that human perception has a relation to the mechanical properties of fabrics, whether it is a perception of single hand elements or complex hand expressions.

These psychophysical studies described have found fact-based quantitative solutions to construct the perception of tactile comfort, bridging the gap between subjective experience and objective data. The precedents set by tactile comfort research provide a solid foundation upon which studies of comfort perception through other sensory modalities, such as vision, can build, extending objective comfort measures into new sensory domains.

2.2.2 Visual Stimulus Influencing Comfort Perception

The systematic categorization of fabric hand elements and the meticulous implementation of descriptive sensory analysis, has erected the bridge between the tangible aspects of fabric to the subjective experience of comfort. As reviewed in Section 2.2.1, there is a substantial body of the theory and practice of how fabric as tactile stimulus affects comfort perception. This foundational understanding now sets the stage for exploring how visual stimuli from fabrics similarly impact comfort perception, an area that has begun to draw interest in current research.

Some psychophysical studies have shown that the look and touch of softness are perceived to be similar. Cavdan et al. (2021) examined softness perception across varied materials and objects, assessing attributes like deformability, fluidity, hairiness, granularity, and roughness under three conditions: haptic, static visual, and dynamic visual (showing hand-material interactions). They found that three softness dimensions, namely surface softness, granularity, and viscosity, could be perceived similarly in all three conditions. Additionally, deformability and roughness were also perceivable in dynamic visual and haptic conditions. They concluded that the visual information that showed interactions with materials might be effective in communicating the haptic experience. Yang et al. (2014) compared three different modalities, that is touch only, vision only (viewing video with fabric fluttering in a wind) and a combination of touch and vision for the fabric softness evaluation. They found the consistency of the main physical determinants, the bending, shearing, and surface properties measured by KES-F, in all three modalities. These properties were in equivalent proportion in touch only modality. The bending property played the key role in the other two modalities. The research indicates that the fabric hand perceived by the visual-tactile sense could be used for objective evaluation.

Furthermore, Jimba et al. (2021) explored how fabric dynamic draping (rotating) behavior and fabric physical properties influence visual judgment of softness. They used the changing angle of fabric drape to represent dynamic draping behavior. Their results suggested the feasibility of predicting the visual rating of softness by fabric bending rigidity. Bi et al. (2018) built a simulated animation visualizing fabrics with varied stiffness blown by wind in randomly sampled directions and strengths as visual stimulus, finding that perceived stiffness and physical bending stiffness were highly correlated. Through the analysis of multi frame motion information, they indicated that motion played a vital role in estimating mechanical properties. In addition to the investigation of visual softness perception, more studies proved the feasibility to model fabric physical properties with other visual sensations towards clothing, such as other various visual-tactile attributes of clothing comfort (Chen et al., 2014; Xue et al., 2016) and clothing aesthetics and quality (Phoophat et al., 2019; Watanabe & Horiuchi, 2021) perceived visually. All these findings indicate that fabric physical properties can be regarded as a mediate linkage between visual and tactile comfort perception, and it is possible to estimate fabric physical properties by showing proper visual stimulus.

In terms of visual stimulus expressing the appearance of material texture, however, some other studies suggested that visual stimulus activates a more independent sensation different from tactile perception, meaning visual sense could be the pillar of perception to generalize the whole profile of the sensed texture in the absence of touch (Picard, 2006; Whitaker et al., 2008a; Whitaker et al., 2008b; Ciesielska-Wróbel & Van Langenhove, 2012; Sun et al., 2016). This point of view is contrary to the above-mentioned, challenging the notion that visual and tactile perceptions are closely aligned. The controversy stems from the multi-dimensional nature of sensorial comfort and a lack of comprehensive empirical data. It is empirically correct that visual sensation can reflect tactile experience, like the experimental case stated previously, but this function is most likely to be limited to the ones related to fabric mechanical properties, such as softness (Yang et al., 2014; Cavdan et al., 2021). While optical information (such as lighting and color) is important in the motion-based visual perception results, motion information and shape deformation of soft materials are also indispensable to the visual perception of movement according to the studies by Bi et al. (2018) and Alley et al. (2019). In Bi et al. (2018)'s study, the researchers quantified and manipulated the motion information of a simulated cloth through adjusting video speed consistency. They found that as the speed consistency was increased, the simulated cloth was perceived as stiffer. Alley et al. (2019) simulated falling objects in surprising motion conditions (such as hard objects behaving as soft), letting participants watch the video and rate their perception of materials' tactile properties during different frame times. Their results suggested that the recognizability of the fabric deformed shape influenced the processing of optical information, which in turn affected the generation of tactile sensations associated with materials. The two studies referenced underscore the idea that subjective evaluation of clothing comfort through visual perception is intricately linked to the visual characteristics of the fabric, particularly aspects like fabric deformation and motion.

Building on the concept of interlinked visual and tactile perceptions, another important aspect is that a high correlation between visual and touch perception is a commonly used indicator to describe the high fidelity of visual representation in visual assessments (Wijntjes et al., 2019). It has been found that in general virtual forms of clothing visualization, realistic visual elements have a positive impact on visual-tactile imagery in visual similarity comparisons (Atkinson et al., 2013; Xiao et al., 2016; Xue et al., 2016; Hoedemakers, 2018). Concrete examples of realistic visual elements influencing visual-tactile imagery included detailed presentations of texture with light and shadow to show roughness (Atkinson et al., 2013), and fabric color and folds to improve the accuracy of fabric discrimination (Xiao et al., 2016). Additionally, visual cues such as digitally simulated fabric, designed to demonstrate their appearance in practical applications, can swiftly convey tactile properties to the viewer. (Xue et al., 2016). Furthermore, the use of zoomable virtual fabric interfaces that replicate the experience of handling real fabric could also enhance visual-tactile imagery (Hoedemakers, 2018). These studies mostly recognized and proved that the dynamic clothing presentation communicated comfort sensations more effectively than the static one from the perspective of visual and tactile perceptual correspondence, while general, reproducible conclusions to explain a regular pattern of developing realistic dynamic visual cues are still lacking (Yang et al., 2014; Overmars & Poels, 2015; Hoedemakers, 2018; Wijintjes et al., 2019). Compared to images, motion videos can transmit garment tactile information to a greater extent (Xue et al., 2016). Realistic mechanical motion simulation of virtual fabric is reflected through collisions with other visible or invisible objects in the environment, such as wearers' body, gravity, and wind speed (Schilder, 2008).

This statement could be supported by two concrete research examples from Aliaga et al. (2015) and Bates et al. (2015). Aliaga et al. (2015) conducted two matching tests to analyze if appearance and motion factors contribute to the recognition of dynamic clothing. Bates et al. (2015) tested people's ability to predict the dynamic path of liquid flow by vision. Their research findings both indicated that the perception of realism in a scene with moving soft materials is achieved through physically accurate simulations. These simulations accurately represent both the appearance and motion of the materials and their interactions. Such detailed simulation enables people to visually distinguish fabrics with distinct dynamic characteristics (such as silk). In other words, accurate apparel motion simulation can lead the viewer's perception to visually "touch" the corresponding real product.

2.3 Real-Based 3D Clothing Simulation

In the subsequent sections, the technology of 3D clothing simulation is described in detail. These portions detail the principles behind how 3D simulation technology functions as a tool for creating virtual clothing samples and showcasing clothing products.

2.3.1 Simulating 3D Virtual Apparel for Prototyping Purpose

3D simulation technology has been significantly developed in the clothing industry since the beginning of this century. The applications involved such as virtual collection design and virtual-try-on applications enhanced by augmented reality, have been continuously expanded and extended, and the industry's interest and desire for 3D simulation technology keeps stimulating the potential of the technology for innovation (Santos et al., 2020). In development and production of real clothing, one of the key benefits of 3D simulation technology is the ability to visualize 3D models without needing physical samples, a process known as virtual apparel prototyping.

The term virtual prototyping means developing and testing the artifact that approximates features of a product, service, or system, namely the prototype, on a computational platform (Camburn et al., 2017). Virtual prototyping features a high capability of product communication to share overall information among all participating individuals and organizations and to make the linkage between the physical and virtual approachable in the digital form (Cugini et al, 2008; Camburn et al., 2017). When implemented in apparel development and production, virtual prototyping serves as the convergence between simulation technology and real apparel products by enabling the building of the 3D simulated model using procedures imitating the real production and equipping the model with physical clothing attributes (Lagė et al., 2020). In the current clothing production sectors, there are many 3D CAD tools for the implementation of virtual prototyping. The common operation interface of 3D apparel CAD systems is composed of 2D (flat garment pieces) and 3D workspaces (draped garments), between which modification and editing are interoperable. The ability to rotate, zoom, and adjust the visibility of 3D objects in the 3D workspace provides a 3D perspective for users' observation and multi-view picture export. A consistent workflow to build the simulation by using 3D CAD was proposed as: determination of fabric properties, preparation of virtual mannequin and garment pattern for simulation, virtual sewing, virtual garment try-on, evaluation of the virtual garment fit and appearance on the virtual mannequin (Lagė et al., 2020). Most components to construct the avatar/human-garment model (including virtual fabrics, human body models, and garment patterns) can be created by external input obtained through various scanning and measuring tools or sensors for real attribute detection (Maksimović, 2020; Ork Efendioglu et al., 2021). More details of digitizing real attributes will be reviewed in the next subsections. The technique of inputting real clothing attributes implemented in apparel prototyping represents the mechanism of an out-of-sync digital twin, meaning the virtual garment created does not require a time-synchronized linkage between the virtual and physical world, but focuses on imparting high-fidelity attributes to virtual simulation even if detection is not real-time (Tao et al., 2019). Equipped with characteristic attributes of real people and clothing products, the avatar/human-garment simulated model can be considered as virtual correspondence to be displayed, edited or tested. This is the foundation to further observe the avatar/human-garment model's behavior and performance in simulated scenarios (Bug & Helwig, 2020). Therefore, it has been indicated that the 3D CAD tools for virtual prototyping purposes can simulate digital replicas of clothing products, which has opened a bridge between virtual and reality for visual-tactile-related research. The following section detailed how these 3D human-garment elements are simulated parametrically.

2.3.2 Inputting Real Attributes for Apparel Simulation

Virtualization of fabrics incorporates both graphical effects and physical properties that are input by two independent paths separately (Kim et al., 2021). For a fictive example, it is possible to simulate a virtual fabric using pictures of real leather and physical properties of real silk, but this cannot be called the digitization of real fabrics. The input graphical files and physical parameters originating from the same physical fabric are the requisite to form a qualified digital correspondence of real fabric.

To show the process of clothing virtualization more concretely, the following subsections will review the digitizable attributes of real apparel components and the corresponding digitizing methods and techniques. These contents demonstrate the relationship between real clothing products and their digital counterparts, to lay a theoretical foundation for visual stimuli preparation for the current research.

2.3.2.1 Fabric Mechanical Properties. In the construction of dynamic fabric simulations, mechanical properties of fabrics are key characteristic parameters. These properties not only influence the simulated fabric's deformation but are also vital attributes that correspond to the real fabric's behavior and can be visually perceived (Bi et al., 2019). To simulate a digital replica of a real garment, bending, shear and tensile, and density properties are generally considered as the most important fabric properties to be input, because these three properties characterize fabric deformation under different stress conditions, so that they largely affect the simulation fidelity of apparel's fit and draping behavior (Ancutienė & Sinkevičiūtė, 2011; Sanad & Cassidy, 2015; Kuijpers et al., 2020). Specifically, research studies conducted by Ju and Choi (2020) have shown that stretch, shear, bending, and density properties in CLO significantly influence the virtual fabric characteristics. They implemented a feature vector representing the boundary curve of the drape as a drape shape indicator, to investigate the relationship between fabric drape and six CLO fabric parameters related to stretch, shear, and bending properties. They obtained the parameter sets from 400 various virtual fabrics derived from real knit fabrics and found out these parameters were strongly related to fabric drape shape in both weft and warp directions.

Building on the exploration of fabric drape, Hussain et al. (2020) investigated an objective approach to estimate fabric hand using drapes of real fabrics and established objective ranks based on drape indicators using principal component analysis. Their results showed that fabric drape is a viable alternative to fabric hand. Bouman et al. (2013) also conducted a perceptual experiment to observe human's ability to estimate fabric stiffness and density from videos and images and found that judgment results obtained by subjects watching the video were consistent with the real stiffness and density of the fabric. The collective findings from these research cases underscore an interconnection between the mechanical properties of fabrics—such as bending, shear, tensile, and density—and the visual manifestation of fabric drape. This relationship is pivotal in both virtual and real-world contexts: in simulations, these mechanical properties are essential inputs that dictate the fidelity of a garment's fit and draping behavior, and they may similarly influence the perception and assessment of fabric hand, as observed in physical scenarios.

While these virtual fabric parameters are crucial for simulating the deformation of fabric in digital replicas, Kuijpers et al. (2020) added a nuanced perspective. Their review on measuring techniques for fabric digitalization suggested that these techniques should correspond to the scene when fabric is worn on a person, which is a different measure focus compared to the ones of standard fabric objective measurement systems that have been frequently used in assessing real touch of fabric (such as KES-F). In the standard objective measurement systems, the indicators characterizing fabrics' response to force are measured to reproduce subjective fabric hand feeling, which is more related to real contact.

In the realm of bending tests, for example, 3D apparel CAD companies, such as FAST, CLO Fabric Kit and Optitex Testing Kit, follow the cantilever principle to test fabrics' bending performance, which targets apparels' state of hang and drape to test fabrics' bending performance. This approach features streamlined test methods and simplified data outcomes compared to the KES-F-represented, mainstream measuring systems (Kuijpers et al., 2020). Although the bending tests following the cantilever principle are more functionally suitable, it may not perfectly retain the full picture of real fabric bending performance. The mainstream bending tests can represent the test result as a parametric curve, which is more flexible for analysis, and is more precise in observing the bending pattern of fabrics under various values and direction of force over a period of time (Maksimović, 2020). Nevertheless, the continuous data in huge volume could cause the running burden to CAD systems, so this precision is not practical for apparel simulation purposes.

Moreover, tensile and shear tests for fabric simulation are mostly integrated as a single stretch test to measure the extension of the fabric under different directions of tension (Luible & Magnenat-Thalmann, 2007; Kuijpers et al., 2020). Kuijpers et al. (2020)'s review on fabric property testers for simulation use showed that fabrics' tensile and shear performance can be precisely measurable, but the precision varies depending on fabric types and digitizing operation. To sum up, the current objective fabric measurement methods can obtain complex and accurate fabric properties relevant to apparel's fit and draping behavior, but the visual complexity has not been proved to be effective from the perspective of viewers' visual-tactile perception.

In addition, comparisons between commercial and laboratory fabric mechanical property measuring instruments revealed differences in standardization and precision . Maksimović (2020) specifically evaluated two representative measuring systems for virtual apparel simulation use, namely KES-F and CLO Fabric Kit, to compare their testing precision and testing protocol in measuring the same properties. According to the result of his SWOT analysis, KES-F is a more sophisticated, professional system to test tensile, shear, and friction properties for representing fabric drape. However, the instrument is pricey and requires high-level operation, and the properties are measured in a state that is not like how clothing is worn, thus the possibility that it could be popularized in the fashion industry has been questioned. CLO Fabric Kit is the opposite, as it provides convenience in testing operation, while its accuracy and stability performance are not the most ideal for establishing industrial standards (Maksimović, 2020). Similarly, by studying the derived parameters of extensibility, shear rigidity and bending rigidity tested by FAST and Browzwear Fabric Test Kits respectively, Power (2013) found the incompatibility of bending rigidity conversion between the two systems. Both Kuijpers et al. (2020) and Power (2013) pointed out that the commercial fabric test kit released by these companies lack standardized testing methods to ensure the stability and reproducibility of the results, which remains an unsolved issue.

2.3.2.2 Visual Fabric Texture. In virtual simulation of clothing appearance, the term fabric texture mainly refers to visual appearance. According to Kumar (2020a), texture means "the digital representation of the appearance of a surface" of a fabric obtained or created from an actual sample manipulated in a graphic (p.43). In virtual simulation, visual fabric texture refers to repeated structures across the surface of simulated fabric. As the workflow to build a 3D apparel simulation described by Lagė et al. (2020) mentioned previously, assigning the appropriate fabric properties to the apparel model is the first step in input file provisioning, while the properties including appearance can also be modified in the later process. Also, according to the texturing guide by Kumar (2020b), there are two types of texture, 2D and 3D. The former is a bitmap display. The procedure of 2D texturing is like applying a printed sticker to the surface of 3D models, which is a straightforward way to obtain 3D models with rich colors but lacks precision. Unlike the 2D texturing technique, 3D texturing represents a significant advancement in generating textures (Kumar, 2020b). This method allows for the parametric creation of textures with much finer details. Currently, it is predominantly utilized by 3D CAD tools.

Through applying various combinations of texture maps to fabric surfaces, the technique of 3D texturing can simulate realistic and detailed optical appearances of fabrics. According to the theory of Physically Based Rendering (PBR), these maps respectively represent different behaviors of light interacting with material surfaces, to simulate the uniqueness of a certain fabric textures (McDermott, 2018). Taking CLO, one of the commonly used apparel 3D CAD software, as an example, there are six maps available in fabric property settings to be customized. They are texture map, normal map, displacement map, optical map, roughness map and metalness map as Table 2 demonstrates their definitions and looks in detail. Fabric texture simulation usually starts with a texture map picture input. Figure 1 summarizes virtual fabrics' varying visual effects after each additional map has been applied to overlay with the texture map using CLO and using the example picture shown in Table 2.

Table 2

Six Texturing Maps in CLO

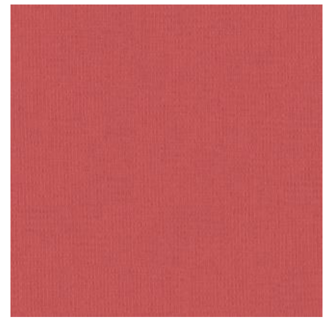
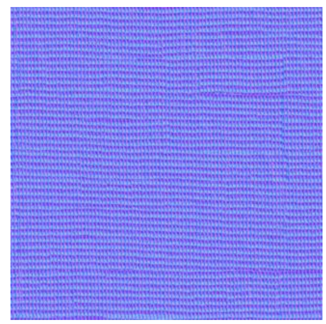
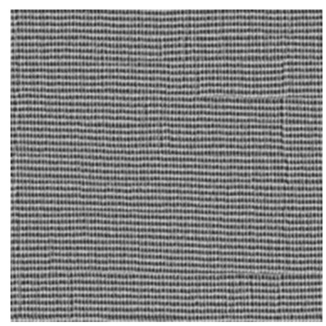
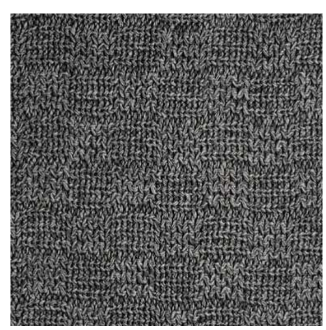
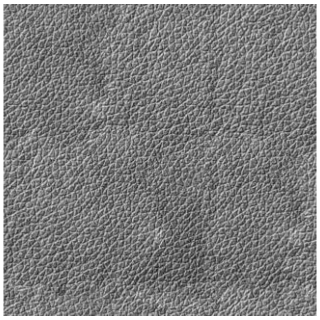
Map name	Definition	Example
Texture map	Texture map is the most important map that largely determines fabric appearance. It defines the main color and motifs of the surface.	
Normal map (bump map)	Normal map transforms fabric texture into a bump shape to add a three-dimensional effect to virtual fabric, instead of additional geometry to the surface. The map file looks purple.	
Displacement map (height map)	Displacement map gives the illusion of depth by showing displacement of the mesh. The map file looks gray, where the darker area means lower displacement. In the settings of CLO, the value of "amount" changes the visibility of the height.	
Opacity map (alpha map)	Opacity map defines the transparency and translucency of the fabric area. The map file looks gray. The darker area appears more transparent in the simulation.	

Table 2 (continued)

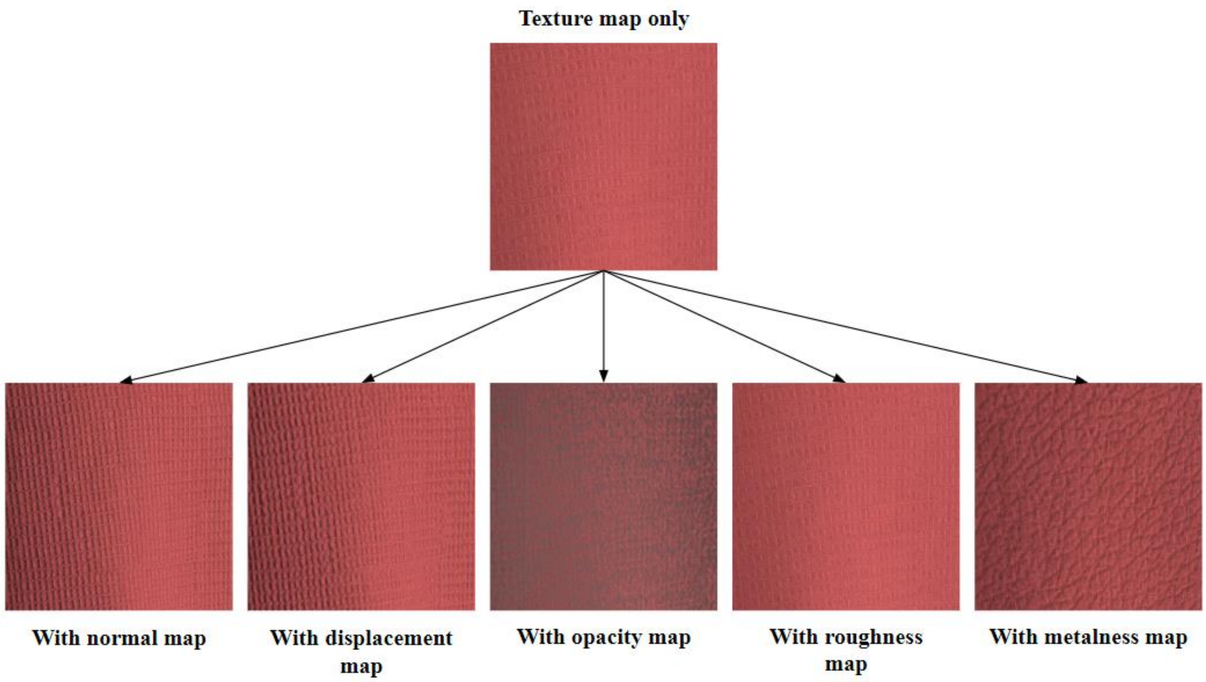
Six Texturing Maps in CLO

Map name	Definition	Example
Roughness map	Roughness map controls light information. The map file looks gray, where the lighter area makes fabric appear more shiny and reflective.	
Metalness map	Metalness map gives fabric metallic shine, meaning it only reflects the metal color. The map file looks gray, where the lighter area has more metallic reflection.	

Note. adapted from Jiang and Chen (2017); Kumar (2020b); BobbinTalk (2022).

Figure 1

Texture Effect with Each Map Applied



Note. Created by the author. The fabric swatches displayed at the arrow tips were exclusively generated by applying each of the specified maps individually to the single texture map swatch presented above.

2.3.2.3 Simulating Garment Ease and Movement Test. As mentioned in Section 2.1, in garment construction, the spacing between the clothing and wearer, called garment ease, ease allowance or ease of movement, is a factor closely related to comfort perception of clothing movement in real wearing cases. Ng et al. (2007, p.236) classified garment ease to three levels. The first is “comfort ease” to satisfy wearers’ basic movement, such as breathing and sitting; the second is “movement ease”, meaning the dynamic ease allowance for completing extreme postures; the third is “styling ease” for the purpose of achieving designed silhouette only. The developers of functional garments and activewear usually target the second level, the “movement ease” and perform Range of Movement (ROM) tests, to investigate if the apparel product has sufficient mobility and comfort when the wearer is doing the physical activities or exercise tasks assigned. As a concrete example of performing ROM test, Huck et al.

(1997, as cited in Fan, 2004) set an exercise protocol consisting of a series of body movements to evaluate the fit of protective overalls on live models. The measurements included the visual observations emphasized by the researchers, and the wearers' acceptability scale completed by subjects.

In the 3D CAD workspace containing virtual apparel simulation, in the absence of a real model, visual observations become dominant for evaluating garment ease, and the 3D CAD software provides virtual apparel makers with a more objective view of how clothing interacts with the human body (Smallman et al. 2001; Tao et al., 2014). For example, the garment model is simulated by virtually sewing the digital pattern pieces to be draped on the avatar, with the virtual fabric applied, so the spatial relationship between clothing and wearer (virtual avatar) can be visualized in the 3D window (Smallman et al. 2001). Moreover, a way of displaying data in layers called color map in 3D CAD software presents the distribution of ease data through the clothing and the avatar's body, which is helpful in optimizing garment fit in virtual apparel prototyping (Tao et al., 2013). With the assistance of these 3D CAD functions mentioned, Cheng et al. (2020) performed a complete virtual prototyping workflow to produce a male underwear, involving the idea of a virtual ROM test. They used the CLO Strain Map to check the fitting of the underwear in multiple poses, and they modified the value of fabric tensile parameters based on the simulated compression effect in the CLO Stress Map. Liu et al. (2018) proposed a way to design garment ease in virtual apparel simulation. They enlarged the default avatar to a bigger one with the value of ease added in the cross-section diameter of five key body levels, bust, waist, hip, thigh and ankle. Their study showed that garment ease of virtual apparels can be visually simulated and observed in a flexible fashion with the help of 3D CADs' virtual simulation and data visualization techniques (Liu et al., 2018). The operation for simulating, observing, and analyzing garment ease could be more convenient compared to ROM tests using live models. These studies presented the reliability of using 3D CAD to explore spatial relationships between humans and apparel for current research.

Most of the research on avatar movement, on the other hand, has predominantly focused on the static posture of virtual clothing and avatars. Morlock et al. (2019) argued that the postures for garment ease and comfort evaluation in the virtual ROM test are not reproducible enough to specify for permanent use, while few studies have made progress in exploring changing garment ease in animated virtual apparel simulation. In the use of 3D CAD, avatar and apparel models are animated starting with avatar rigging. Avatar rigging means assigning or adjusting positions for static avatars' joints, to prepare the avatar for being animated. The animating operation requires a motion file to be bound with the static avatar, so that the avatar can become a kinetic one performing the motions with the joint positions assigned in chronological order (Zhang & Krzywinski, 2019). With the establishment of the kinetic avatar, 3D CAD further animates the draping and moving behavior of apparel into the motion video, usually up to 30 FPS (Frame Per Second) for a smooth quality (CLO, 2020).

The joints involved, planes of motion, moving speed, etc. can all vary with the motion types, causing countless apparel deformation (Mooney, 2017). While data-driven simulation could standardize motion types for apparel evaluation, few standardized postures and movements are currently available as virtual motion files with open access to research (Zhang & Krzywinski, 2019). A relatively feasible criterion to determine the postures and state of movement for testing is to focus on the end-use of the apparel (Jin & Black, 2012). For example, Doty et al. (2017) delineated the yoga poses to test the mobility and comfort of real yoga apparel using visual data. Compared to yoga-focused apparel, activewear generally involves a wider range of wearing situations, so it is more difficult to develop a full list of representative poses for testing a vision-based mobility and comfort of activewear. Nevertheless, the end-use principle remains important in determining the poses and state of movement to use in task performance evaluation tests both in real and in virtual, and also in designing activewear product motion display (Abuhav, 2017; Bug & Helwig, 2020).

2.4 Evaluation Tools of Current Research

This research aimed to explore how U.S. consumers of women's activewear perceive clothing movement when watching simulated 3D apparel in motion, and the relevance of their perception to virtual fabric properties. This research was guided by three primary research questions:

- RQ1: What aspects of virtual fabric properties influence clothing movement perception?

- RQ2: What are the descriptors to show how consumers evaluate clothing movement in the context of 3D apparel motion simulation?
- RQ3: What are the virtual fabric properties that are most impactful to visual perception of clothing movement?

While RQ1 focused on selecting virtual fabric properties for testing in the 3D design stage, RQ2 and RQ3 delved into the visual evaluation stage, involving human perspectives in appraising 3D apparel simulations. To address these questions, a mixed-method approach was implemented. A focus group study method was conducted to explore RQ2 qualitatively, followed by a MaxDiff Conjoint survey to gather quantitative data on the most impactful aspects of apparel simulation for RQ3. The subsequent sections discussed the suitability of these methods for developing and evaluating the research findings.

2.4.1 Focus Group Study

A focus group is a technique using in-depth group interviews where participants are purposively sampled from a specific population to discuss a given topic (Rabiee, 2004). The focus group study method has been generally applied to explore possible areas of focus for product development and merchandising based on consumers' needs and perception (Yang, 2007, as cited in Bordegoni, 2011; Dawson & Kim, 2010; Jervis & Drake, 2014). Compared to individual interviews, it can produce information more efficiently at a lower cost, in a shorter time, and with fewer participants involved (Liamputtong, 2011; Jervis & Drake, 2014). In a research study focusing on consumers' conceptualization of apparel attributes, Abraham-Murali and Littrell (1995) stated that a major purpose of focus group interviews was to unearth a wealth of information from customers' vocabulary. This coincides with the consideration of using a focus group method in this study. RQ2 is a "what?" type of question that requires answers grounded in detailed descriptions of perceptions and experiences. A focus group study method is appropriate for generating a good quantity of descriptive words about what consumers can be visually perceived from watching virtual apparel simulations (Abraham-Murali and Littrell, 1995).

In general, qualitative data analysis includes three main steps: 1) preparing and organizing the data, 2) coding the data into categories/themes, and 3) representing the data (Creswell, 2007). Evaluating focus group data starts with organizing and transcribing discussions, highlighting key phrases and important points. The next step is coding, where responses are grouped into categories based on existing literature codes, or on emerging codes from the current discussions, or both. The final step involves summarizing categories into clear themes, using participant quotes for emphasis, and relating them to existing research.

2.4.2 MaxDiff Conjoint Approach

Conjoint analysis is a method that presents respondents (usually consumers) with a designed set of hypothetical product profiles whose attributes and corresponding levels are carefully specified, to collect their preferences in the form of ratings, rankings, or choices for those profiles (Agarwal et al., 2015). According to the instructive guide of Steiner and Meißner (2018), the idea of conjoint analysis is to mimic real world decision-making scenarios by requiring consumers to make trade-offs between product concepts in comparison. The application field of conjoint analysis has been not limited to so-called market research but has been expanded to broader purpose of capturing consumers' perception, interaction and experience with products so far (Thomas & Chambault, 2016; Ribeiro et al., 2020). It is a useful medium for respondents to give their feedback on more than one attribute of the product composite.

Conjoint analysis method is the umbrella term for a set of specified approaches, which includes but is not limited to Choice-Based Conjoint Analysis, Menu-Based Experimental Choice and Maximum Difference Scaling (also called Maxdiff Scaling, Maxdiff Conjoint or Best/Worst Conjoint) (Agarwal et al., 2015). Steiner and Meißner (2018) have suggested that Maxdiff Conjoint, that is an extension of conjoint analysis method of paired comparison, is applicable in obtaining attribute importance weights, and lets researchers access more attributes compared to other conjoint analysis approaches. In the use of Maxdiff Conjoint approach, multiple discrete objects (also called discrete choice sets) are presented at a time, and the respondent selects both the most and the least attractive objects in a series of objects (Louviere et al., 2015, as cited in Almli & Næs, 2018). Instead of direct rating in other methods, such as Likert Scaling, a ranking generated according to the frequency of selection counts attribute importance, which makes Maxdiff Scaling less prone to measurement bias due to respondents' estimation inconsistency (Agarwal et al., 2015; Pinto et al., 2019).

There are applications of Maxdiff Scaling in research related to consumers' visual preference. McLean et al. (2017) conducted maxdiff exercises to investigate the influential visual cues of different packaged bacon that drive consumers' purchasing decisions. They arranged the questions with bacon photos of varying fat content as options. Dobbie and Farrelly (2022) presented street photographs as Maxdiff Scaling's visual stimuli to collect data about landscape preferences. In addition, in an investigation of consumer preferences for organic apples, Adamsen et al. (2013) compared pictorial and textual representations of product profiles with multiple attributes used in Maxdiff questions. Their findings suggested that using graphics to present choices of the Maxdiff questions makes it easy for people to perceive, understand and make decisions.

Within the use of MaxDiff, marginal utility scores are crucial, functioning as measures of an attribute's relative appeal or value. Attributes with higher scores are seen as more influential in determining choice preferences (Sawtooth Software, 2020; Han et al., 2023). These scores, often zero-centered for ease of interpretation, are readily available from analysis software like JMP, representing refined versions of initial utility scores (JMP Help - MaxDiff, 2023). It is important to note that a negative score doesn't imply an attribute's lack of importance, but rather its comparatively lower significance relative to attributes receiving positive scores. Additionally, the concept of marginal probability, derived from marginal utility, is employed to calculate the percentage of total importance that each attribute contributes. This marginal probability, or equivalently the marginal utility, can serve as an analytical variable in advanced evaluations, such as cluster analysis (Han et al., 2023), to segment products based on similar features or market positioning. Therefore, the further use of marginal probability or utility scores facilitates a more nuanced exploration of the distribution patterns of MaxDiff scores, offering deeper insights into how various attributes are perceived and valued.

MaxDiff scores can be encoded into categorical variables, with the highest preference marked as 1, the least as -1, and non-selections as 0. This coding enables the integration of MaxDiff outcomes into predictive modeling, for example, regression modeling (Demirtas et al., 2009), to probe into the relationship between consumers' preference levels and product features.

The aforementioned studies in this literature review have implications for identifying the status quo of clothing-movement-relevant studies, and for building the methodologies of the current research to solve the three research questions.

- Section 2.1 organized a relatively sound body of theoretical knowledge to explain clothing movement as a vision-based clothing comfort. This section analyzed the definition and positioning of clothing movement in the field of sensorial comfort, and clarified the textile and clothing factors that may be impactful to the perception of clothing movement.
- Section 2.2 further described how clothing as visual stimuli could be studied by following the research path of tactile clothing comfort, and how visual cues of clothing influence visual perception of clothing movement. This section is of important guiding significance for the experimental thinking of this research.
- Section 2.3 explained how apparels' visual features are simulated through the input of real components, to provide a theoretical and technical basis for using animated virtual apparels as an experimental medium. The implementation of technologies for fabric digitalization and avatar and apparel animation were thoroughly described.
- Section 2.4 discussed the appropriateness of using a mixed, step-by-step research method to approach the answers of the three main research questions. Combining qualitative and quantitative research methods, the variety and sequence in the data collecting would help to find the compatible and conflicting parts in data, thus making the output of data analysis more practicable.

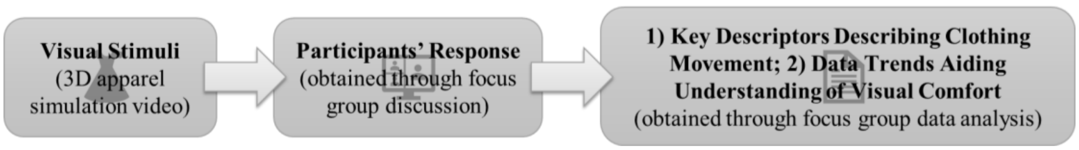
3. METHODOLOGY

3.1 Overview of Proposed Research Path

This research implemented a mixed method primarily consisting of a focus group study and a survey that utilized Maxdiff Conjoint analysis in two phases, specifically Phase 1 and 2. Figures 2(a) and 2(b) provide a concise overview of the experimental procedures for these two main phases.

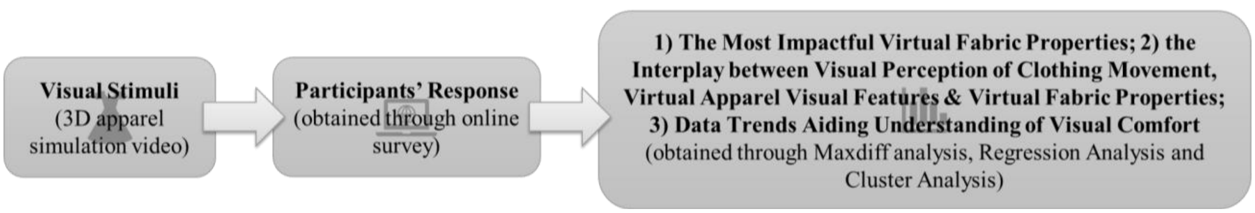
Figure 2 (a)

Overview of Phase 1: Focus Group Study



(b)

Overview of Phase 2: Maxdiff Conjoint Online Survey



Note. Figures 2(a) and 2(b) provide a schematic representation of the experimental procedures across the two main phases. Figure 2(a) illustrates Phase 1, wherein two focus groups, each comprising 7 to 10 individuals, observed the simulations for discussion. This phase yielded insights into visual-tactile descriptors, and any data trends aiding understanding of visual comfort. Figure 2(b) elucidates Phase 2, during which about 100 online participants answered Maxdiff Conjoint survey questions. The outcomes of this final phase included identifying the most impactful virtual fabric properties, elucidating the interplay between visual perception of clothing movement, virtual apparel visual features and virtual fabric properties, and discerning data trends that facilitate the understanding of visual comfort.

Prior to Phase 1, a pilot focus group study was conducted as Phase 0A. The aim of the pilot study was to test the feasibility of the qualitative exploration approach employed in Phase 1, and to gain a holistic understanding of the empirical connection between visual perception of clothing movement and impactful virtual fabric properties. Additionally, a simulation test was also involved as Phase 0B to narrow down the adjustable virtual fabric parameters in apparel simulation software, thereby setting the groundwork for visual stimuli construction in Phase 1. The thorough map of the entire research process spanning from the initial phase to the final phases is detailed in Table 3.

Table 3

Map of Research Process

Research Aim of Each Phase	Methodology & References
Phase 0A: To evaluate the smoothness and efficiency of the focus group process planned for Phase 1.	Focus Group Study Abraham-Murali & Littrell (1995); Dawson & Kim (2010); Brunyé et al. (2012); Speight et al. (2019)
Phase 0B: To address the first research question by referring to previous research cases and conducting a simulation test to investigate the impact of adjusting variables that affect virtual fabric properties in apparel simulation software on the visual representation of simulated fabric.	Observation
Phase 1: To address the second research question (RQ2) by extracting descriptive words that reflect the perceptions of U.S. consumers of women's activewear regarding simulated clothing dynamics as visual stimuli.	Same as Phase 0A
Phase 2: To address the third research question (RQ3) by identifying the most impactful virtual fabric properties influencing visual perception of clothing movement, and to examine the connections among these visual perception, observable features of virtual apparels, and virtual fabric properties.	MaxDiff Analysis, Regression Analysis, Cluster Analysis Demirtas et al. (2009); Speight et al. (2019); Han et al. (2023)

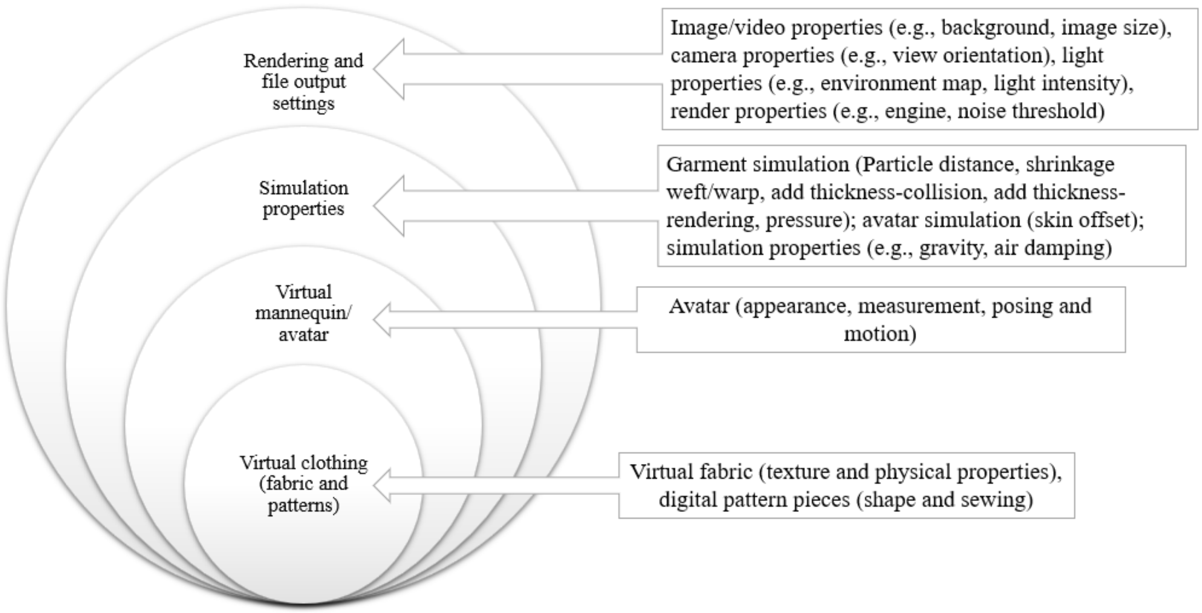
3.2 Technical details of 3D Apparel Simulation in CLO software

All 3D apparel simulation and animated videos used in this study were produced using CLO software. For Phase 0A, Phase 0B and Phase 1, CLO Version 7.1 was used, whereas CLO Version 7.3 was utilized for Phase 2. Per the feature overview from CLO, no alterations were made to simulation properties pertinent to this research between these versions (CLO, 2023d). The computer used for creating 3D models and videos is equipped with an Intel(R) Core(TM) i7-9850H CPU @ 2.60GHz 2.59 GHz processor and a NVIDIA Quadro T2000 graphic card.

CLO software involves various virtual setup parameters to complete a 3D apparel simulation video, which are organized in a nested relationship from micro (virtual clothing) to macro (rendering and file output settings) design objects, as depicted in Figure 3. This diagram is based on a summarized workflow of building 3D apparel (Lagė et al., 2020) and CLO software instructions. The present research focused exclusively on variables that pertain to the "virtual fabric," which encompassed both the "texture and physical properties" under study, as shown in Figure 3. Configurable items for setting texture and physical properties in the CLO working environment are listed in Figures 4(a) and (b). Texture properties are set to express the surface appearance of the virtual fabric, while physical properties control the virtual fabric's physical performance, particularly when it comes into contact with other simulated objects (e.g., avatar) within the simulated physical environment. The ability of the virtual fabric to withstand external forces and resist deformation, for instance, are key aspects of its physical performance that are governed by its physical properties. The classification of texture and physical properties has been detailed in Section 2.3.2.

Figure 3

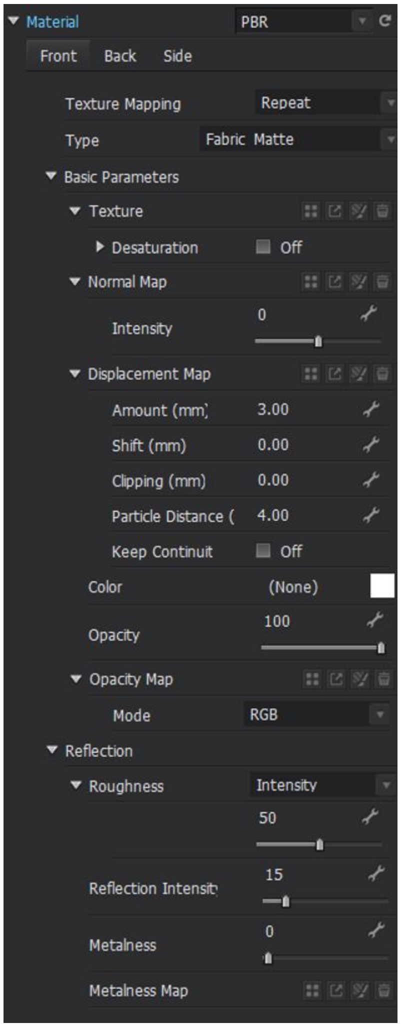
CLO Virtual Setup Parameters in a Nested Relationship



Note. Created by the author. This diagram shows a range of virtual setup parameters for creating a 3D apparel simulation video in CLO, arranged in a nested structure. This summary is based on the 3D apparel construction workflow by Lagė et al. (2020) and incorporates guidelines from CLO software.

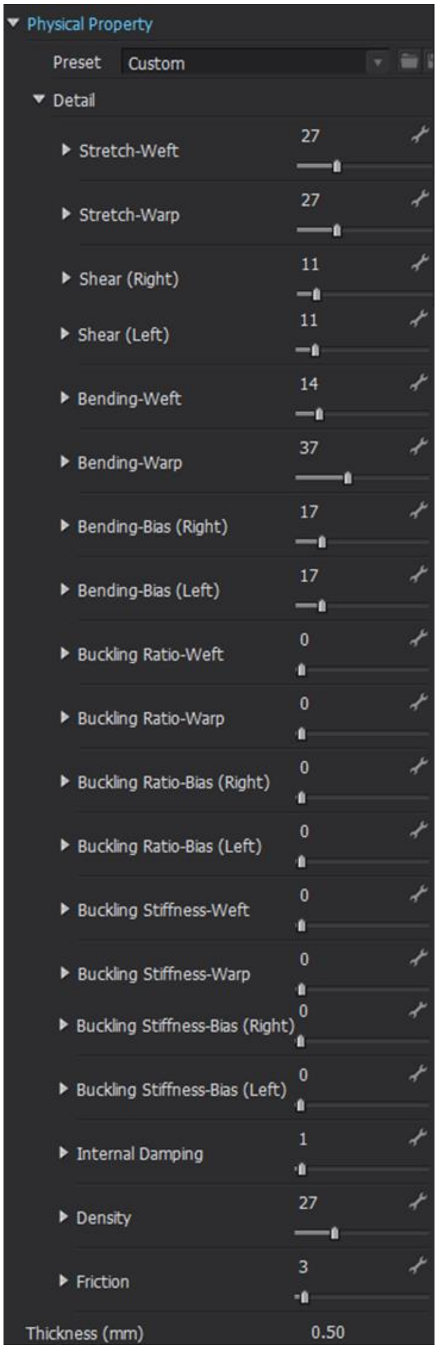
Figure 4(a)

A Screenshot of CLO Virtual Fabric Texture Setting Items



(b)

A Screenshot of CLO Virtual Fabric Physical Property Setting Items



3.3 Phase 0A: Pilot Focus Group Study

A pilot focus group discussion was conducted to test the fluency of experimentation and the possibility that the knowledge expected could be obtained. The data achieved in this pilot study contributed to improvements to the experimental design details (such as the guiding questions) to ensure a large enough number of respondents' words or ideas effective for answering the first two research questions (RQ1 and RQ2) could be generated in Phase 1's focus group discussions.

The pilot study differed from the focus groups conducted in Phase 1 in that the simulation videos showcased a broader variety of clothing types, fabrics, and avatar movements within the context of the activewear scenario. Seven virtual activewear fabrics were downloaded from the FABRICAST™ digital fabric library by Cotton Incorporated to be used for simulation. The clothing types modeled in the simulations included both tops and bottoms, one-pieces, variations with and without sleeves, and items with tight versus loose fits. Avatar movements within the simulations included actions such as dancing and jumping, to span a spectrum from relatively low to high speeds. All movements involved the whole body, providing a holistic view of clothing behavior in dynamic scenarios.

In the pilot study, four female students aged 19 to 28 passionate about shopping for sportswear participated in a one-hour Zoom session. Before discussion started formally, they were asked to upload screenshots specifying the display settings and relevant hardware specifications of the devices used. During the session, participants initially shared their perspectives on evaluating the mobility, functionality, and comfort of activewear when shopping online. Subsequently, they were shown six videos featuring virtual apparel simulations in motion. Notably, these simulations incorporated a broader range of fabrics, colors, and avatar movements compared to what was planned for the main study. The rationale behind this expansive selection was to capture a comprehensive spectrum of initial reactions, ensuring a thorough understanding of potential variables influencing the visual perception towards simulated clothing movement. This broader range during the pilot phase served as an exploratory measure, providing insights on the significant fabric types, color combinations, and avatar movements that evoked consistent or noteworthy feedback.

During the focus group, the moderator managed the video playback, sharing each clip in a randomized sequence. As discussion for a given video neared completion, the subsequent video was introduced. To ensure accuracy of capturing the nuances of the conversation, the audio was transcribed into text using Otter.ai (2024), an AI-driven voice transcription service. The resulting draft was then meticulously cross-referenced with the video recording, ensuring participants' personal details were de-identified and nuances, such as response timings and whispered comments, were accurately captured. With the research questions as a guide, the transcript underwent several reviews to establish thematic categories and discern overarching relationships among them.

3.4 Phase 0B: Simulation Testing to Select Virtual Fabric Properties

While many parameters can be adjusted in CLO software to control virtual fabric properties, it is impractical to examine all relevant variables. This study focused on the CLO virtual parameters, *stretch and shear*, *bending* and *density* to facilitate the analysis of the effect of these selected variables. The selection of these variables was because these properties of real fabric have a significant impact on fabric drape and movement appearance, and further affect the tactile feeling of fabric (Bouman et al., 2013; Ju & Choi, 2020; Hussain et al., 2020).

To obtain further evidence supporting the assumptions drawn from the literature and to investigate how virtual fabric parameters can impact visual perception, Phase 0B, a preliminary exploration of visual effects brought by adjusting virtual fabric parameters, was conducted within CLO. The exploration aimed to discern how these virtual fabric parameters were typically adjusted in CLO, and how they differed from real fabrics, as well as the consistent patterns emerging when each parameter was modified and its visual implications on fabric. Results from the Phase 0B activities and how they influenced the subsequent phases are detailed in Chapter 4.

3.5 Phase 1: Focus Group Study

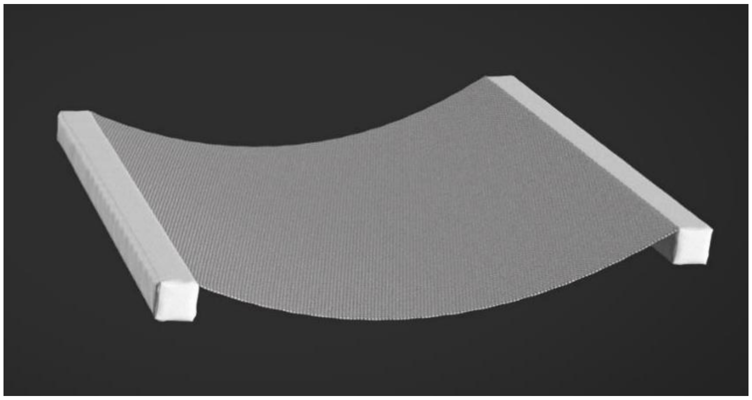
In Phase 1, a focus group was employed to explore how U.S. consumers perceive movement in women's activewear during 3D apparel simulations. As reviewed in Section 2.4.1, the focus group study method was used for efficiently gathering insights on consumer needs and perceptions, offering a cost-effective alternative to individual interviews by obtaining information more rapidly with fewer participants (Abraham-Murali and Littrell, 1995; Dawson & Kim, 2010; Speight et al., 2019). The primary objective of this phase was to gain a comprehensive understanding of the visual assessment of clothing movement and to determine the descriptors associated with it.

3.5.1 Visual Stimuli Construction

During the focus group discussion, participants were presented with two types of video clips demonstrating virtual clothing animation. The first type of video featured fabric simulation in a clothing piece as Figure 5 shows. The virtual clothing piece resembling a rectangle fabric specimen and measuring 60 cm × 64 cm, was hung between two sticks. While one stick remained stationary throughout the animation, the other was animated to induce movement in the fabric. The entire animation spanned three seconds, translating to 90 frames in total. The movement peaked at the first second (frame 30) as the stick reached its maximum point of motion. By the next second (frame 60), the stick had returned to its starting position, with the remaining duration being static. There were three variations in motion: pulling, sliding, and twisting. For the pulling animation, the mobile stick elongated the fabric to twice its original length before reverting. For the sliding animation, the stick was moved horizontally to a distance double its initial position and then retracted. The twisting animation featured the stick rotating 90 degrees around the midpoint before returning to its original orientation. By merely altering the moving or rotating directions of the stick, videos displaying these three action variations were produced.

Figure 5

Simulated Video in Clothing Piece Type (Initial Frame)

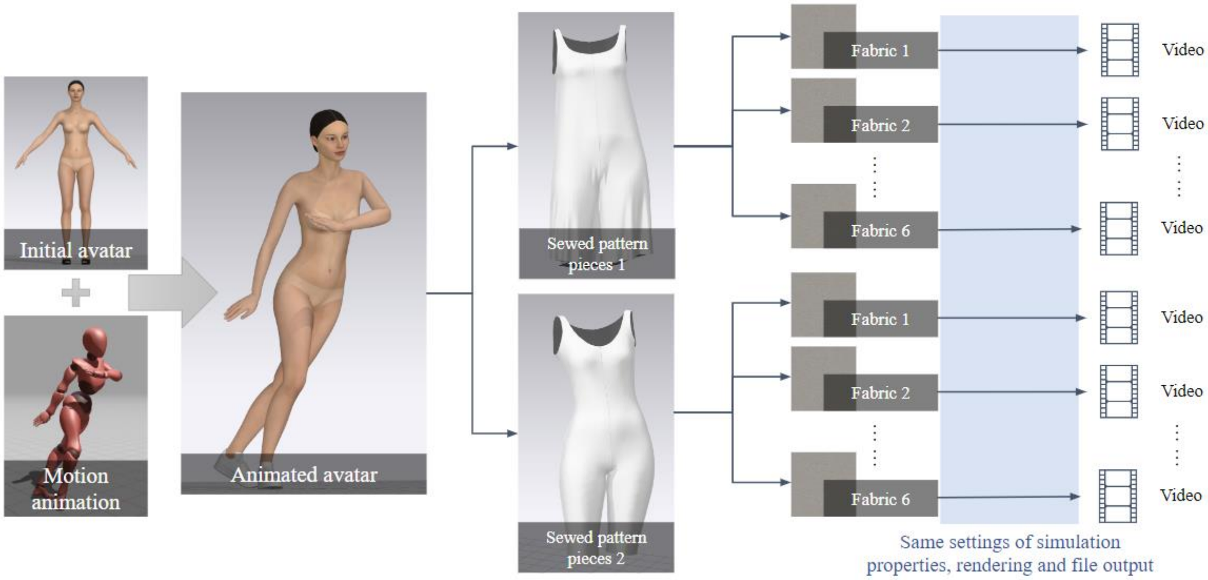


Note. This figure demonstrates the setup of the simulated clothing piece as seen in the initial frame of the video. Within this setup, the right stick remains static for the duration of the animation, and the left stick is animated to simulate movement, engaging in actions of pulling, sliding, or twisting.

The second type of video simulated fabric on a moving activewear garment, with its production process depicted in Figure 6. To animate the garment, a female avatar was selected from CLO, and uploaded to Mixamo, a cloud-based 3D animation service by Adobe (2024), to obtain an automatically rigged full human skeleton, enabling the application of animation to the avatar. Subsequently, the animated avatar was imported back into CLO software to drape the virtual garment onto the model. The virtual garment was constructed by sewing together pieces assigned with virtual fabrics of varied properties. This process resulted in an animation video showcasing virtual apparel in motion, achieved by simulating and combining the apparel's virtual state for each frame in accordance with the time sequence. The simulation and rendering properties were set to produce a high-quality simulation with acceptable production efficiency. All virtual pieces were draped in CLO using the "fitting (accurate fabric)" simulation quality setting. For animation, the "animation (stable)" simulation quality was employed, with both nonlinear simulation and GPU simulation activated to simulate more authentic stretching behavior. Throughout this process, a consistent particle distance of 5 mm was maintained.

Figure 6

Production Process of Simulated Video in Apparel Type



During each focus group, participants were presented with six sets of videos, each featuring different virtual fabric variants listed in Table 4 as Fabric 1 (F1) to Fabric 6 (F6). All virtual fabric variants originated from the same initial virtual fabric, one of the seven digital fabrics used in Phase 0B. The selection of this initial fabric was derived from the findings of Phase 0A, where the focus group discussion highlighted that the surface appearance of this particular virtual fabric is highly textured and features a contrasting color with the background, allowing it to better reflect the fabric's movement details. As shown in Table 4, the fabric variants in the sets represented contrasting groups with low and high values of stretch and shear, bending and density properties. The low and high values were determined based on the results of property adjustment and simulation tests conducted in Phase 0B, ensuring a notable difference in the observable dynamic behavior of the clothing pieces, covering as much of the 0 to 100 parameter range as feasible. Each set had five videos showcasing the fabric in various clothing displays, including three videos demonstrating the fabric clothing piece's ability to be stretched (pulled), sheared and bent (twisted), and two videos featuring the female avatar dancing in a tight and loose jumpsuit made from the same fabric.

Table 4

Fabric Variants for Focus Group Study

Order	Fabric Variants	Contrasting Groups	Values of Specified Parameters' Coefficients
1	F1: Stretch and shear - low	F1&F5	Stretch - weft: 10 Stretch - warp: 10 Shear - right: 10 Shear - left: 10
2	F2: Bending - high	F2&F4	Bending - weft: 80 Bending - warp: 80 Bending - bias right : 80 Bending - bias left: 80
3	F3: Density - low	F3&F6	Density: 10
4	F4: Bending - low	F2&F4	Bending - weft: 10 Bending - warp: 10 Bending - bias right : 10 Bending - bias left: 10
5	F5: Stretch and shear - high	F1&F5	Stretch - weft: 80 Stretch - warp: 80 Shear - right: 80 Shear - left: 80
6	F6: Density - high	F3&F6	Density: 80

3.5.2 Sampling Method

University students studying apparel and textiles who were active consumers of women's activewear were recruited via college distributed emails. The reason for this selection is that these students have familiarity with clothing and textiles through their coursework, so their description of fabric and apparel facilitates the acquisition of high-quality discussion data. The insights provided by the student participants in the pilot study support this selection approach, demonstrating that their academic background in clothing and textiles contributes to the richness and relevance of the data collected for current study. Moreover, students are likely to be interested in online shopping and novel displays of apparel products, which fits well with the research objectives (Jeong et al., 2009). The potential participants completed a pre-validation survey through the recruiting email distributed, including consent forms to sign and questions about themselves, online shopping habits and their availability to participate in a focus group.

3.5.3 Phase 1 Focus Group Procedures

With the continuous impact of the COVID-19 pandemic, Phase 1 focus group discussions were held online to ensure the stability of the experimental plan. The discussions were audio and video recorded using Zoom. To maintain consistency in the viewing experience, participants were required to use a desktop or laptop with full computer screen display, rather than mobile devices, to access the online session. This precaution aimed to minimize variations in the size of visual stimuli viewed by participants. Two groups were recruited. The first group consisted of 8 participants, with an average age of 24.25 (minimum: 20, maximum: 34), while the second group comprised 7 participants, with an average age of 26 (minimum: 20, maximum: 33). To ensure relevant participants, a pre-validation survey was conducted to confirm their regular engagement in online buying or browsing activities, as well as their usage of women's activewear. Both focus group discussions lasted approximately 1 hour and 20 minutes.

During each focus group session, participants were initially asked general questions to express their experience and opinions regarding the visual assessment of mobility, functionality, and comfort of activewear when shopping online, and whether they had encountered 3D simulation used in online shopping. Their responses provided insights into how current consumers perceive these aspects of activewear and introduced them to the topic of 3D simulation as a means of displaying apparel products. They were then introduced to the 3D apparel simulation videos, presented in the specified order. The moderator provided prompts and informed the participants that they were free to request a replay of any video if they wished to review or verify any visual information. The participants engaged in guided discussions to express their viewpoints until the discourse on each set of simulated videos approached saturation. The guiding question samples were:

- In general, when you shop activewear online, how do you evaluate the mobility, functionality, or comfort of the apparel you see?
- Could you describe the fabric you see from the simulation for me?
- Could you provide more description of how the fabric moves in this video?
- As you've experienced, you can't touch the simulated garments and fabrics right now or even try them on, but you probably have some judgments about the feeling of wearing them. Could you talk about the mobility and comfort of activewear as you see from the simulation?

The questions were designed to elicit as detailed responses as possible to capture participants' perception of apparel mobility, functionality and comfort, and their views about the dynamics of human-apparel simulation when they watched the videos.

3.5.4 Phase 1 Focus Group Data Collection

During each focus group, the simulation video clips were presented in a set sequence corresponding to the fabric variant order in Table 4. For each fabric variant, videos were shown in the following order: fabric pulling test, shearing test, twisting test, tight activewear, and loose activewear. To counter potential issues associated with this fixed sequence, the moderator occasionally revisited earlier videos during the discussion. This was done by the moderator seeking confirmatory feedback with questions like "do you mean this?" or by posing comparative inquiries such as "how about this?" The aim was to foster an overarching impression after the complete viewing experience, aiming to minimize the impact of memory retention sequence (Luo & Collins, 2023). Participants also had the freedom to ask for replay of any video to review or verify visual information. Due to technical constraints, simultaneous playback of multiple videos was not feasible. This limitation hindered direct comparison between fabrics but assured the consistency of video frame sizes during each playback. The moderator ensured the discussions approached saturation for each set of simulated videos.

3.6 Phase 2: Online Survey using MaxDiff Conjoint Approach

Building upon the findings of Phase 1, Phase 2 aimed to examine the connection between virtual fabric parameters and the descriptors presenting clothing movement determined in Phase 1, and to identify the most impactful aspects of virtual fabric parameters that influence visual perception of comfort. To achieve this, the principle of Maxdiff Conjoint approach was utilized to create additional sets of virtual apparel motion simulations presenting various combinations of clothing-movement-relevant visual features. As reviewed in Section 2.4.2, implementing Maxdiff Conjoint approach can efficiently collect data and ensure on-target results (Adamsen et al., 2013; Han et al., 2023). Moreover, this approach aligns with the pilot focus group study participants' perceiving behavior: they evaluated multiple visual cues simultaneously to estimate the overall clothing movement perception. The evidence indicates that Maxdiff Conjoint approach is a suitable method for achieving the study's context and purpose.

The study conducted a MaxDiff Conjoint online survey targeting a broader women's activewear consumer group among university students studying apparel and textiles, a group that aligned with the participant profile from Phase 1. The survey participants watched and compared the simulated videos to evaluate their visual perception of clothing movement based on the descriptors obtained in Phase 1. Utilizing Maxdiff analysis, regression analysis and clustering analysis, the most influential factors were distilled based on participants' evaluations.

3.6.1 Observer Variability Evaluation and Psychophysical Method Design

Evaluating observer variability is essential in research involving new measurement methods (Deng et al., 2022). Especially in online survey contexts where control over participants' viewing environments is limited, this limitation requires meticulous attention to variability in the responses collected via an online Maxdiff visual comparison experiment. Additionally, careful use of psychophysical methods is important to ensure high completion rates, especially when these methods are utilized in MaxDiff assessments, where attributes are repeatedly presented across questions, potentially leading to visual fatigue due to repetitiveness (Adamsen et al., 2013).

The current study employed interobserver and intraobserver variability measures to evaluate the consistency and agreement of responses (Deng et al., 2022). Interobserver variability refers to the variation in responses among different observers viewing the same phenomenon, while intraobserver variability gauges the consistency of responses from the same observer over repeated assessments.

To evaluate the visual perception survey conducted online, a smaller group of participants was additionally recruited to complete the same survey in a controlled laboratory environment. The uniformity in display systems, such as monitor settings, lab lighting, viewing distance, and angle, was ensured for result comparability.

For assessing interobserver variability, descriptive analysis focused on the consistency of choices among participants. The variance from both online and in-lab groups were used to explore preference variations. Intraobserver variability was examined by analyzing responses to one set of repeated survey questions, comparing the consistency of individual participants' choices. The result of the intraobserver variability was expressed as a ratio, indicating the percentage of online survey participants who provided consistent answers to the repeated questions.

The study aimed to gather a comprehensive data set from 95-105 online participants, ensuring robustness in evaluating interobserver variation. This sample size was driven by the practicality of recruiting volunteer participants and adjusted based on a power analysis. This analysis considered expected large and medium effect sizes, adhering to Cohen's established norms (0.8 for large and 0.5 for medium effects) (Rahlfs & Zimmermann, 2019). To detect a large effect, the projected requirement is around 25 participants, while for a medium effect, it is close to 63. Thus, recruiting approximately 100 participants exceeds these estimates, enhancing the study's power to a level well beyond the 80% initially aimed for at a 0.05 significance level.

In designing the survey, the duration was capped at 10 minutes to strike a balance between the thoroughness of the evaluation and participant engagement. This optimization led to the inclusion of only one duplicate question to assess individual consistency. The brevity of the survey was strategically considered to optimize completion rates while still capturing essential data for observer variability analysis.

3.6.2 Survey Construction

The survey employed the MaxDiff Conjoint approach to evaluate how viewers perceive and value different attributes of 3D simulated apparel in motion. These attributes included CLO virtual fabric *stretch and shear*, *bending*, and *density*. In each question within the survey's main section, participants encountered a series of questions prompting them to select from a set of three videos presenting different fabric variants that best and least corresponded with the given descriptors. Through their choices across all questions, participants essentially ranked the videos, providing a comparative assessment of each fabric variant's alignment with the descriptors. The survey was developed utilizing the Qualtrics platform and has been included in its entirety as Appendix F. The surface appearance of the virtual fabrics used in the survey was consistent with the ones in the focus group discussion of Phase 1.

The attributes—*stretch and shear*, *bending*, and *density*—were manipulated across two levels: *low* and *high*. No reliable resources are currently available to quantitatively indicate how these coefficient values correspond to the intensity of each fabric property. Therefore, the construction of the simulated fabric in this step was based on the extreme high and low parameter settings identified in Phase 0B, specifically using the range of 10-80 to grade each virtual fabric attribute. It was anticipated that fabrics simulated using these varied property extremes could be visually differentiated informed by the focus group discussions from Phase 1. This approach led to the determination of the coefficient values of each CLO parameter, as presented in Table 5.

Table 5

Description of Full-Profile Choice

Attributes	Levels	Coefficient Values of CLO Parameters
Stretch and Shear	Low – High	Stretch – weft: 10 – 80; Stretch - warp: 10 – 80 Shear - right: 10 – 80; Shear - left: 10 – 80

Table 5 (continued)

Description of Full-Profile Choice

Attributes	Levels	Coefficient Values of CLO Parameters
Bending	Low – High	Bending – weft: 10 – 80; Bending - warp: 10 – 80 Bending - bias right: 10 – 80; Bending - bias left: 10 – 80
Density	Low – High	Density: : 10 – 80

Given that there were three attributes with two levels each, eight attribute combinations resulted. Consistent with full-profile Conjoint Analysis, all attributes were presented in each question (Conjointly, 2022). Each attribute combination appeared at least three times across the surveys to ensure the reliability, resulting in nine choice sets as illustrated in Table 6.

Table 6

Choice Set Design for Video Production

Set	Attribute Combination 1	Attribute Combination 2	Attribute Combination 3
1	V1 (A1B1C1)	V2 (A1B1C2)	V3 (A1B2C1)
2	V4 (A1B2C2)	V5 (A2B1C1)	V6 (A2B1C2)
3	V7 (A2B2C1)	V8 (A2B2C2)	V1 (A1B1C1)
4	V2 (A1B1C2)	V3 (A1B2C1)	V4 (A1B2C2)
5	V5 (A2B1C1)	V7 (A2B2C1)	V8 (A2B2C2)
6	V1 (A1B1C1)	V6 (A2B1C2)	V7 (A2B2C1)
7	V3 (A1B2C1)	V5 (A2B1C1)	V4 (A1B2C2)
8	V2 (A1B1C2)	V8 (A2B2C2)	V7 (A2B2C1)
9	V6 (A2B1C2)	V1 (A1B1C1)	V3 (A1B2C1)

Note. In this table, *A* denotes *Stretch and Shear*, *B* signifies *Bending*, and *C* represents *Density*. The numerical value *2* corresponds to *High*, while *1* indicates *Low*.

The survey incorporated three descriptors of visual comfort paired with visual feature description of clothing movement. The descriptions allowed participants to assess how the videos resonated with the context of a simulated avatar wearing the clothing. The exact wording of these descriptors, as used in the survey, is displayed in Table 7 and was derived from Phase 1's findings of the research. A total of 30 questions were included, enabling participants to provide a complete ranking of the eight simulated videos in relation to the three targeted descriptors, with a duplicated comparison to evaluate the internal consistency of the responses.

Table 7

Descriptors of Visual Comfort and Corresponding Clothing Movement Description

Descriptor	Description
Flexible – not flexible	"Flexible" refers to the fabric's ability to "move with the body".
Supportive – not supportive	"Supportive" refers to the fabric's tendency to gap and wrinkle: the more it gaps and wrinkles, the less supportive the fabric is considered.
Comfortable – not comfortable	No specific description is provided,

3.6.3 Data Collection

The survey was conducted online and in a laboratory setting, to maximize both reach and reliability. The online component brought the convenience of digital accessibility, reaching a wider range of student respondents that mirrored potential consumers of 3D apparel simulations, thus enhancing the generalizability of the findings. Conversely, the physical lab survey served as a control, offering a set of data for comparison to validate the assumption that variations in viewing equipment do not significantly impact result accuracy.

Apart from nearly 40 instances of uncompleted survey, the online study successfully collected complete response data from 96 participants, who were purposely sampled from the university students representing consumers of women's activewear in the U.S. market. In the beginning of the survey, they were asked whether they browse/shop/use online women's activewear, as well as their academic year and major to confirm the eligibility of their participation. Then they signed the consent forms before entering the main body of the questionnaire. They completed in an average time of roughly 10.45 minutes. The survey was accessible online from November 4th to December 26th, 2023.

In the lab, 18 students enrolled in a course with access to a computer lab equipped with standardized monitor models were recruited for participation. To ensure consistency, participants were instructed to adjust their display settings to a prescribed standard, including monitor brightness, viewing distance, and angle. The researcher was present to oversee these conditions and assist if necessary. The content of the survey was identical in both the online and lab environments, with completion time averaging around 9.08 minutes.

4. RESULTS, ANALYSIS AND DISCUSSIONS

This chapter presents, analyzes, and discusses the findings from each phase of the research. Organized sequentially from Phase 0A to Phase 2, the chapter reflects the research's phase-wise progression. Phase 0A and 0B established a foundation for examining focus group fluency and the construction of visual stimuli for Phase 1, while the conclusion from Phase 1 informed the content of descriptive words and visual stimuli for Phase 2.

This structured overview facilitated distinct analyses driven by the shifting objectives throughout the pilot focus group in Phase 0A and the focus groups in Phase 1. Phase 0A aimed to evaluate the efficiency of the experimental setup and the potential for knowledge acquisition for Phase 1, focusing on identifying the virtual fabric simulation aspects that elicited consistent or noteworthy feedback. The analysis in this phase categorized the data into broad classifications based on shared content characteristics and identified preliminary perceptions of virtual fabric attributes by participants. Conversely, Phase 1 delved deeper into understanding participants' visual perceptions of clothing movement within the virtual clothing context. The analysis in this phase employed a more granular approach, starting with segmentation of the discussions into distinct content areas that discuss specific topics, where the main content area focused on describing visual fabric attributes as visually perceived. Following the identification of these content areas, each content area was coded. Coding involved assigning labels or keywords to specific data segments, such as phrases, sentences, or paragraphs, that capture the essence of the information (Creswell, 2017). The coding process aimed to extract themes, meaning patterns or topics that emerge from the data, signifying significant or recurring ideas (Creswell, 2017). In Phase 1, the key themes were descriptive words that respond to the second research question (RQ2), offering a comprehensive picture of how participants visually perceive clothing movement in virtual clothing simulations.

4.1 Phase 0A: Pilot Focus Group Study

4.1.1 Assessing Experimentation Efficacy and Knowledge Yield

Five categories representing general visual features reflecting virtual simulation setup emerged from the pilot study conversations. They are *The Speed of The Avatar's Movement*, *Color Environment*, *Human-Body-Referred Fabric Displacement*, *Fabric Texture*, and *Garment Fit (Tightness or Looseness)*. The representative quotes of these categories are listed in Table 8. Nearly every visual feature among the five was discussed in broad terms by participants.

Color Environment. The discussions regarding *Color Environment* were notably consistent. All participants concurred that the apparel color and the simulation video's background color should be distinctly differentiated. One representative quote from the discussion highlights this point by saying:

> If the background was like white or a lighter beige or something like that, but not the same color as the right side then I think it would be more easily identifiable like the properties of the garment if I would want to wear it or not.

This feedback suggests that fabric simulations would benefit from avatars wearing apparel colors that starkly contrast with the background color. However, no particular focus was given to the apparel's color during the discussion.

Human-Body-Referred Fabric Displacement. The discussion shows that participants expressed the need to observe the interactive, relative deformation between clothing and body parts to accurately assess clothing movement. They noted the garment's ability to move with the body without slipping or constriction, including the leggings' ability to not slide down ("the leggings are staying in the same place") during movement and the top's straps not slipping off the shoulders ("the strap don't look like they move very much"). One representative quote highlights this directly:

> I think to me, this looks really comfortable. And it also looks like it could be worn for an array of different things, I think because you can see like the garment moving with the like invisible body that kind of portrays to me that it's like flexible in a way that it'll bend with you. And it's not constricting to you, and you're moving in different ways.

This quote also mentioned the visual simulation's effectiveness in portraying the garment's fit and mobility, emphasizing the importance of seeing the garment on the avatar to better understand the garment's behavior in motion and its potential comfort and functionality when worn.

Additionally, *The Speed of The Avatar's Movement*, *Fabric Texture*, and *Garment Fit (Tightness or Looseness)* —whether tight or loose— were perceived to impact the visual perception of clothing movement by participants. Despite these features being highlighted, it's challenging to deduce from the discussion how they directly relate to the visual perception of comfort or clothing movement.

The Speed of the Avatar's Movement. As Table 8 shows, one participant noted the difficulty in assessing clothing movement at speeds that were either too slow or too fast by saying "I wish I could have like slow down a little bit and then I wish the other one could have maybe sped up a little bit at times." The participant also introduced the reason of such consideration:

> One thing that I like about this simulation is the speed of how the garment's moving because I feel like that's more the speed that I'm working out in because I don't do a lot of yoga or pilates or anything like that. So, I like seeing how it moves slow. But I think this is a much better speed than the other shirt that was like jumping around.

This comment suggests that the optimal speed for observing clothing movement could vary depending on the workout scenario for participants. The complexity of visual demands for varying speeds across different movement types was acknowledged, emphasizing the challenge in perceiving clothing movement effectively.

Fabric Texture. The discussions around fabric texture were more general. Participants speculated on the fabric's physical characteristics, such as the presence of hole structures ("It's not like a pure white… (black points or blue points) makes me feel it's the holes on the fabric") or a coated surface ("It's like the fabric has things covered the model") based on the simulated fabric motion. However, the direct impact of these texture speculations on comfort perception remained less clear in the discussion.

Garment Fit (Tightness or Looseness). The participants highlighted the complexity surrounding perceived comfort related to garment fit with preferences for tightness or looseness varying significantly among individuals and activities. The following representative comment mentioned:

> I think it really depends on … what kind of things you're going to wear those clothes. So if I just wearing this piece of clothes for daily life, like go to school or just go out to have lunch and I think that more loose these the garment is, I will feel more comfortable. But if I'm going to do some like high strength sports and I have to be fit my body very perfectly it should not be very loose. It has to be tighter than the than the usual garment.

The above comment also highlights that a looser fit was generally deemed more comfortable in visual estimations. This preference might underscore the subjective nature of comfort and fit perception, further complicating the direct linkage to visual perception of clothing movement.

Table 8

Analysis of Visual Features Highlighted

Categories	Representative Quotes
The speed of the avatar's movement	"But one thing that I like about this simulation is the speed of how the garment's moving because I feel like that's more the speed that I'm working out in because I don't do a lot of yoga or pilates or anything like that. So, I like seeing how it moves slow. But I think this is a much better speed than the other shirt that was like jumping around. I wish I could have like slow down a little bit and then I wish the other one could have maybe sped up a little bit at times."
Color environment	"Yeah, like maybe if the background was like white or a lighter beige or something like that, but not the same color as the right side then I think it would be more easily identifiable like the properties of the garment if I would want to wear it or not."
Human-body-referred fabric displacement	"... the straps don't look like they move very much. They look pretty (can't hear clearly) bottom of the garment for sure. Looks a lot looser. I feel like than the top…" "I think to me, this looks really comfortable. And it also looks like it could be worn for an array of different things, I think because you can see like the garment moving with the like invisible body that kind of portrays to me that it's like flexible in a way that it'll bend with you. And it's not constricting to you, and you're moving in different ways. And so if I saw this, like on one of the websites that I shop at I would think that the fabric is really, like, suitable for different kinds of working out." "You can notice that the leggings are staying in the same place, which I find that really interesting because I feel like anybody who wears leggings often knows that it's, I find a difficulty finding a pair of leggings that you know, fits your waist dry and doesn't slide down if you're running and moving around a lot. And I noticed that that pair is not going down to her waist as she moves."

Table 8 (continued)

Analysis of Visual Features Highlighted

Categories	Representative Quotes
Fabric texture	"It's not like the pure white. It makes some, I don't know, black points or blue points in the fabric. That makes me feel it's the holes in the fabric." "Yeah. The second one. Yeah, this one is kind of reminding me that the texture is the things that are outside the models. It's like the fabric has things covered the model. "
Garment fit (tightness or looseness)	"Okay, I think it really depends on what kind of how to say what kind of things you're going to wear those clothes. So if I just wearing this piece of clothes for daily life, like go to school or just go out to have lunch and I think that more loose these the garment is, I will feel more comfortable. But if I'm going to do some like high strength sports and I have to be fit my body very perfectly it should not be very loose, it has to be tighter than the than the usual garment. So in that kind of situation. I think the looser does not mean it's more comfortable because when you move, the garment might be fall off your body. That's what we do not want to happen. So I think it depends on the things that you're going to wear. I prefer looser garments. Whenever I'm wearing things for comfort, just because it's not pinching at your body in any way. It just falls nicely."

The discussion also involved evaluating conversations around a total of five categories of fabric attribute estimation, that is their visual perception of fabrics' *breathability*, *thickness*, *softness*, *stretchability/extensibility*, and *wrinkles*. The relevant quotes are shown in Table 9 below.

Breathability. Participants commented, "I think the fabrics looks like very thin and breathable", "It's not like a pure white… (black points or blue points) makes me feel it's the holes on the fabric" and "I think the thinner one should be more flexible and more breathable than the thick one". These quotes show that participants perceived breathability with the fabric's visual and tactile qualities, noting thinness and the small points or holes as indicators of good air flow. The discussion suggests participants' preference for thinner fabrics for their perceived comfort and flexibility, contrasting with thicker fabrics believed to offer more support but less breathability.

Thickness. The discussion on thickness reflected a variety of preferences. Participants mentioned that thicker fabrics were perceived as more supportive, while thinner ones were appreciated for their flexibility and breathability. One participant directly pointed this out: "I think that the thicker the fabric is, the fabric is more supportive compared to the thinner one and I think the thinner one should be more flexible and more breathable than the thick one." This might indicate a trade-off between support and flexibility based on participants' individual preference and the nature of the activity.

Softness. Participants described soft fabrics as resembling loose, large t-shirts and appreciated garments that do not appear stiff, suggesting that softness enhances ease of movement and a better fit. Examples of the comments that support this perspective are "The animation is soft, and it's like the large and loose t-shirt that I usually get", and "It just shows that the clothes can move well with your body. They're not super stiff. They look comfortable. They look like they're fitting her well."

Stretchability/Extensibility. The discussion on stretchability highlights its contribution to participants' visual perception of comfort and fit, with specific mention of how simulations showing black and white fabrics allow for clearer visibility of wrinkles. The clear wrinkles in this situation were interpreted as evidence of good fit and flexibility. The representative comment said:

"One thing that I really like in this simulation is how it's black and white. And I feel like you can see the wrinkles a lot clearer in this one, which, like P4 was saying, that shows a lot about the fit and the flexibility. And I totally agree with her. It looks very, very comfortable."

Wrinkles. According to the discussion, wrinkles were perceived to be a visual indicator of several fabric characteristics, including softness, flexibility, and the fit of the garment. One participant mentioned, "I also think that like seeing the wrinkles in the body suit when she would like turn or kind of bend and kind of showed me that it wasn't too like form fitting and like tight that it like couldn't like budge at all." Another participant stated, "I don't know because I see the wrinkles and I saw that these kind of fabric might lack of the flexibility." Another participant commented, "But one other thing that I noticed is that the top looks a little bit tighter, than the bottom of the garment. (the moderator replayed the clip.) There's a little bit wrinkle there. So I might be taking that back."

It seems that participants had mixed interpretations of wrinkles: some saw them as signs of a lack of form-fitting tightness, suggesting comfort and flexibility, while others questioned the fabric's flexibility. The representative quotes supporting this are "I feel like you can see the wrinkles a lot clearer in this one…that shows a lot about the fit and the flexibility…it looks very, very comfortable." versus "I see the wrinkles and I saw that these kind of fabric might lack of the flexibility". The discussion reflected a nuanced understanding of participants that the presence and nature of wrinkles could inform judgments about the material's quality and suitability for different body types and movements.

Table 9

Analysis of Fabric Attribute Estimation

Categories	Representative Quotes
Breathability	"I think the fabrics looks like very thin and breathable. Yeah, it might be comfortable."
	"It's not like the pure white. It makes some, I don't know, black points or blue points in the fabric. That makes me feel it's the holes in the fabric."
	"Oh, so talking about this thickness of the garment, of the fabric, I think that the thicker the fabric is, the fabric is more supportive compared to the thinner one and I think the thinner one should be more flexible and more breathable than the thick one."
Thickness	"I think everybody has their preference on how thick they want a top versus bottom to be or a one-piece if you're wearing that, depending on what you're doing, that really matters to me as well."
	"I think that the thicker the fabric is, the fabric is more supportive compared to the thinner one and I think the thinner one should be more flexible and more breathable than the thick one."
Softness	"The animation is soft, and it's like the large and loose t-shirt that I usually get."
	"And so it just shows that the clothes can move well with your body. They're not super stiff. They look comfortable. They look like they're fitting her well."
	"I think it may be It's because when it moves there are many wrinkles. Yeah, but I think that's what soft fabric will be like."
Stretchability/Extensibility	"Um, one thing that I really like in this simulation is how it's black and white. And I feel like you can see the wrinkles a lot clearer in this one, which, like P4 was saying, that shows a lot about the fit and the flexibility. And I totally agree with her. It looks very, very comfortable."

Table 9 (continued)

Analysis of Fabric Attribute Estimation

Categories	Representative Quotes
Wrinkles	"But I also think that like seeing the wrinkles in the body suit when she would like turn or kind of bend and kind of showed me that it wasn't too like form fitting and like tight that it like couldn't like budge at all."
	"I don't know because I see the wrinkles and I saw that these kind of fabric might lack of the flexibility. I think so, I think that should be cotton or, or some or cotton blend some nylon."
	"But one other thing that I noticed is that the top looks a little bit tighter, than the bottom of the garment. (the moderator replayed the clip.) There's a little bit wrinkle there. So I might be taking that back."
	"And I feel like you can see the wrinkles a lot clearer in this one, which, like P4 was saying, that shows a lot about the fit and the flexibility. And I totally agree with her. It looks very, very comfortable."
	"I think it may be It's because when it moves there are many wrinkles. Yeah, but I think that's what soft fabric will be like."

Based on the responses detailed above, some connections were found between the fabric performance estimation and the visual features highlighted in participants' discussion: Fabric texture may influence the perception of breathability, because some participants mentioned that the fabric texture with clear structural look (such as holes, mesh) made them perceive the fabric to be air-and-water-permeable. The discussion also suggests that clear fabric texture also increased participants' visual impression of fabric stretchability. Moreover, the looseness of the garment made participants perceive the fabric as soft. Overall, it can be seen from the pilot study that the visual impression of the simulation potentially influenced clothing movement perception, indicating the feasibility of Phase 1's focus group study.

4.1.2 Implications for Phase 1

Few descriptions to depict mechanical behavior of moving clothes were obtained in this pilot study, which was unexpected based on the previous research findings about "attributes describing movement" by Griffiths and Kulke (2002, p.254) . Instead, participants in this pilot study more frequently used generalized, perceptual words (such as comfortable, fit) to directly describe their perceived wearing feeling of comfort, skipping the discussion about clothing's dynamic appearance. Therefore, in the focus group discussions of Phase 1, one of the aims was to enhance the quality of participant feedback on clothing movement. To facilitate more detailed descriptions of garment dynamics, targeted questions and descriptive prompts were included. These were for situations where participants might not spontaneously describe in-depth observation details. For instance, participants were asked, "Can you describe how the drape of the top changes with the avatar's movement?" Such guiding questions were added to the moderator's notes for Phase 1.

In addition, in terms of the fluency of experimentation, asking participants to upload screenshots indicating display settings did not go smoothly in the pilot study. Participants were confused about this step and took considerable time to find the window required in their system. There were no observations in the pilot study to show the perceptual differences presented by the different display devices and settings used as well. Given this, uploading screenshots indicating participants' display settings was omitted in Phase 1.

In conclusion, preliminary results affirmed the feasibility of the focus group study under the proposed experimental approach, aiming to examine the objectivity of clothing movement perception in the context of 3D apparel motion simulation. During Phase 1's focus group discussions, the moderator would need to steer participants more actively toward detailing the movement of the simulated garments.

4.2 Phase 0B: Simulation Test to Select Virtual Fabric Properties

4.2.1 Testing the Principle of Select Virtual Fabrics Properties

To understand how the adjustment process of virtual fabrics' *stretch and shear*, *bending* and *density* parameters in CLO compares to real-life fabrics, and to identify any consistent trends observed when adjusting each parameter, including the visual effects on the fabric, the researcher conducted tests on these parameters in CLO, listed in Table 10 (Ju & Choi, 2020; CLO, 2023a). In these test, the researcher experimented with virtual fabrics by both designing new ones in CLO or using pre-existing CLO fabric files. These parameters were adjusted to check if changes in one parameter would affect others. Through this manipulation, it was found that each parameter is an independent variable that is not affected by other parameters related to fabric surface or structure. This is different from real-world fabrics, where changing one property can often impact others.

Table 10

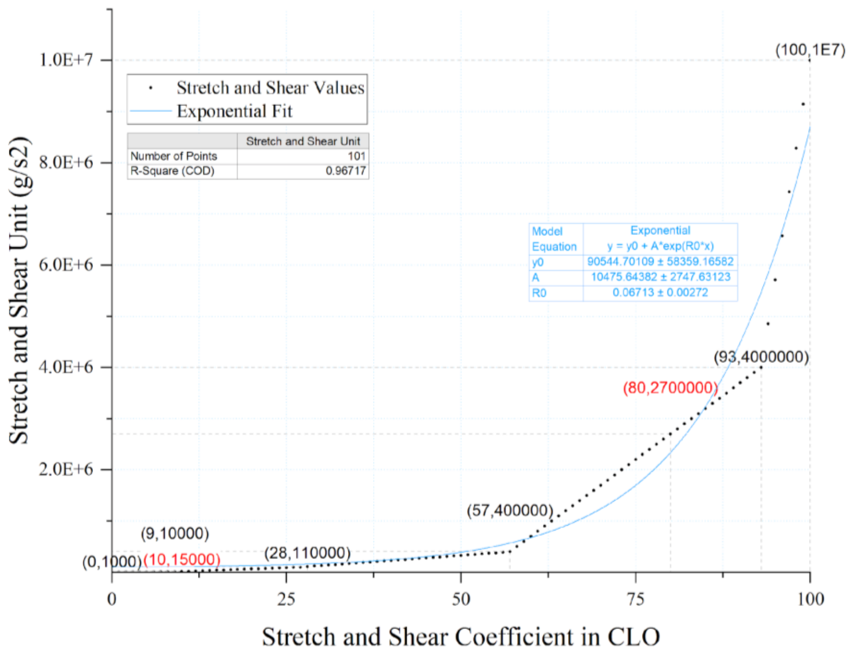
CLO Parameters Relevant to Stretch, Shear, Bending and Density

Property	Parameters	Units
Stretch and shear	Stretch – weft; Stretch - warp Shear – right; Shear - left	stiffness (g/s2)
Bending	Bending – weft; Bending - warp Bending - bias right; Bending - bias left	stiffness (g*mm2/s2)
Density	Density	g/m2

These CLO parameters listed in Table 10 can be adjusted using two units of measurement that are interoperable. The first unit, a coefficient, is a natural number ranging from 0 to 100 that is specifically used in CLO and commonly adjusted in 3D clothing modeling, as it represents a readily accessible option within the CLO's interface, to provide users with a straightforward means of influencing the physical properties of virtual fabrics (CLO, 2024). The second unit is the common unit of measurement, which corresponds to the physical property shown in the third column of Table 10. By entering a coefficient value between 0 and 100, the relationship between the two units of measurement was illustrated in Figure 7 (a), 7(b), and 7(c) below, with the x-axis representing the coefficient value and the y-axis representing the value in common units. It was observed from the three figures that the relationship between the coefficient and the common unit is a simplified exponential relationship for each parameter. In each figure, the scatterplot marked by black dots represents the actual values as displayed by CLO, and the blue curve illustrates the model of fit to these data points. In the three exponential fits, the R-squared values suggest the models' robustness in capturing the data variance: the *Stretch and Shear* parameter is explained with and R-squared value of approximately 96.717%, the *Bending* one with about 98.601%, and the *Density* with about 93. 842%.

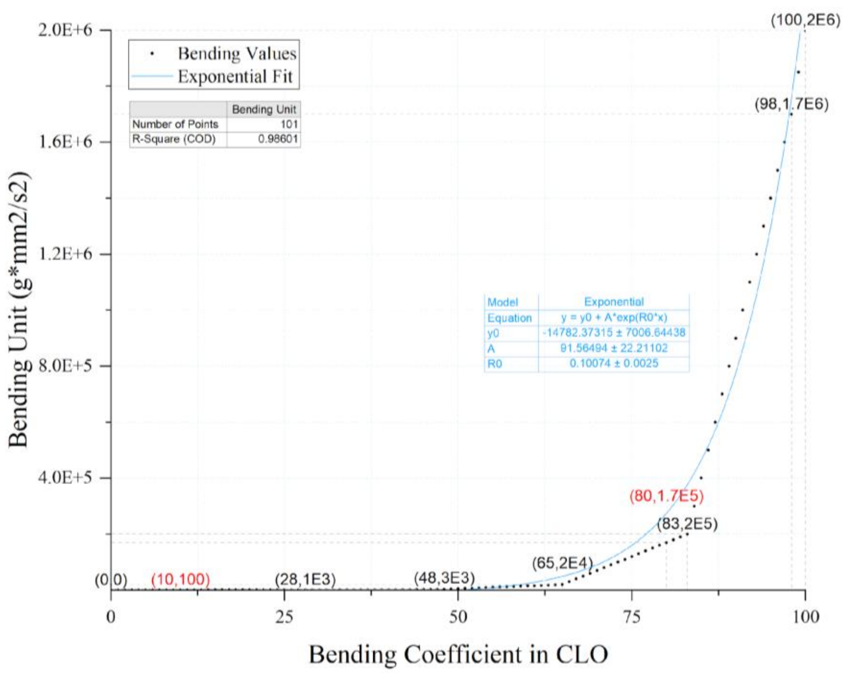
Figure 7 (a)

Relationship between Coefficient and Common Unit of Measure: Stretch and shear



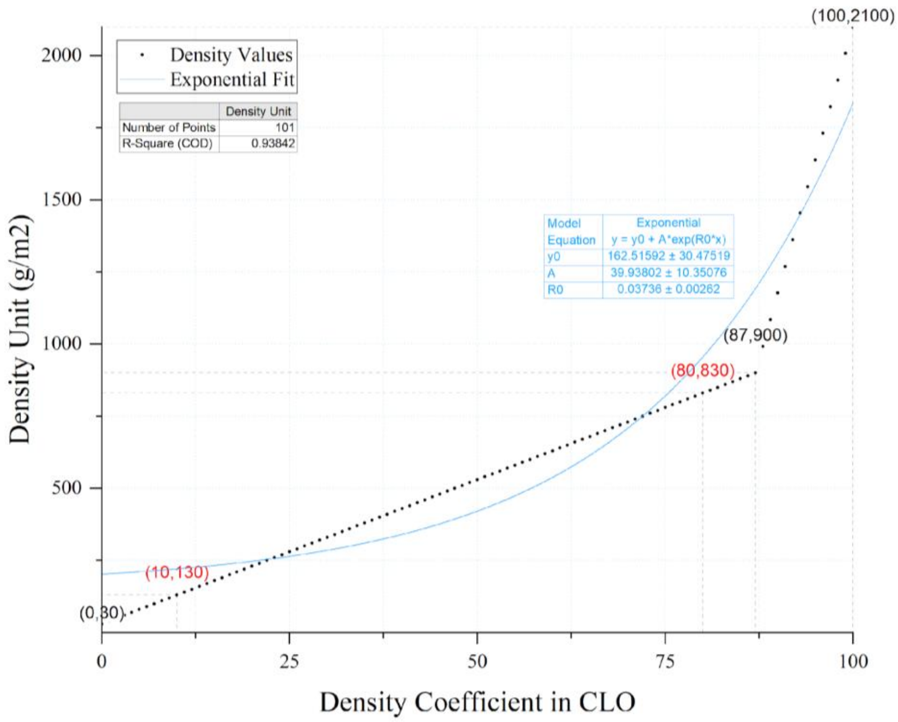
(b)

Relationship between Coefficient and Common Unit of Measure: Bending



(c)

Relationship between Coefficient and Common Unit of Measure: Density



Note. All three exponential models are described by the equation in the blue equation box in each figure, outlining the mathematical relationship between the values of the coefficient and the measurements in common units for each parameter tested. The red points and point labels correspond to the low and high values that were determined for Phase 1's virtual fabric simulations. This distinction was established to ensure a significant difference in the observable dynamic behavior of the simulated fabric.

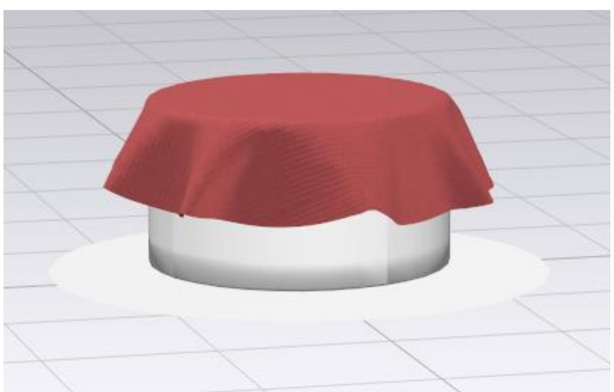
4.2.2 Testing the Visual Effects of Select Virtual Fabric Properties

The testing process described above revealed the independence of the *stretch and shear*, *bending*, and *density* parameters in CLO. This finding allowed for the individual assessment of each parameter's effect on clothing appearance. To facilitate this investigation, seven virtual activewear fabrics, same as those utilized in the fabric simulations during the pilot focus group study, were downloaded from the FABRICAST™ digital fabric library by Cotton Incorporated to be used as virtual specimens. These seven fabrics were then used as initial files, with their variants generated by adjusting the parameters of *stretch and shear*, *bending* and *density*.

To observe the effect of the *density* property, the virtual fabrics were simulated in a 3D environment that mimicked the Cusick Drape Test (see Figure 8(a)) (Youn et al., 2024). The simulation properties were set as shown in Figure 9 to produce a high-quality simulation, and three objects were built in the 3D environment: a virtual fabric sample in a circular piece, a cylinder as the platform for supporting the sample, and a circle plate of the same shape and size as the fabric sample for creating a representation of the initial fabric. To capture the static draping appearance, the fabric sample was placed on the cylinder with the centers aligned with each other. After the simulation was turned on, the researcher waited for the fabric to be completely still and then took a screenshot from the bottom view (see Fig.8(b)). Using the bottom view provided a more intuitive way to see the shape retention of the fabric in the draped state (Mitsuo et al., 2016). The current research conducted this operation to obtain the draping appearance of 70 virtual fabrics (7 initial fabrics + 63 density variants).

Figure 8 (a)

Simulated Cusick Drape Test



(b)

Example of Draping Appearance

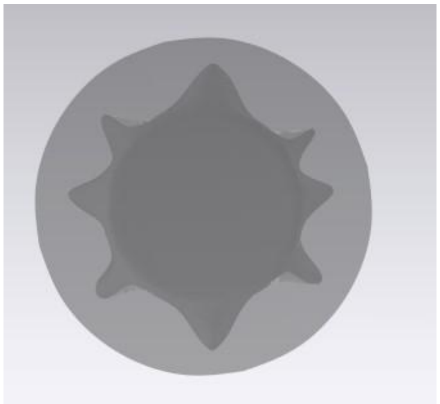
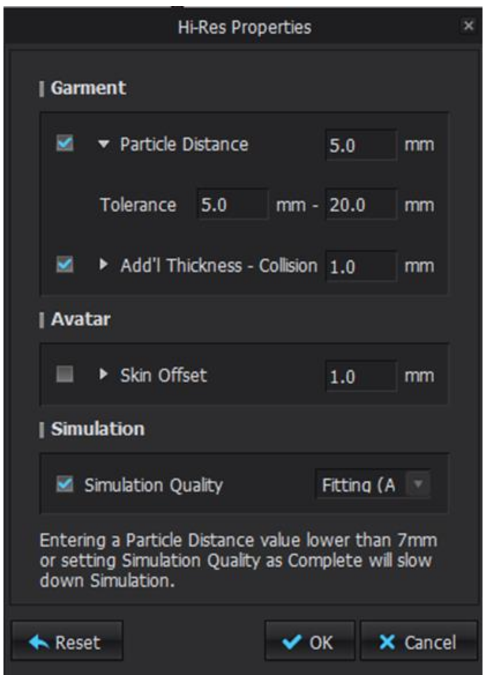


Figure 9

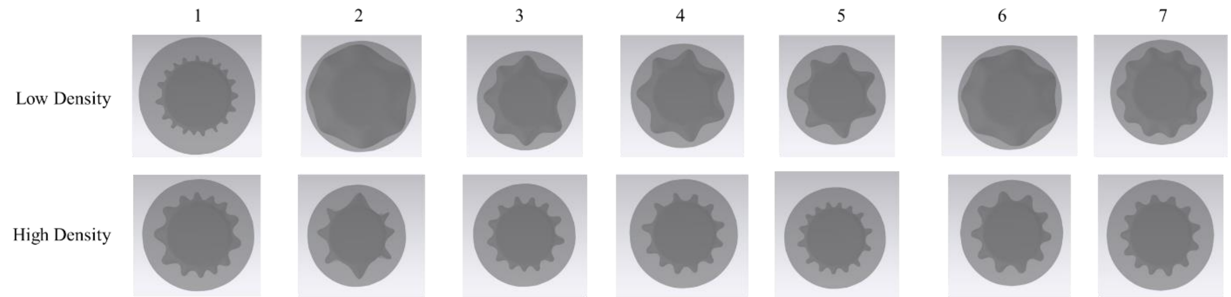
High-Quality Simulation Properties



The test result showed that visual differences in fabric drape between the different density values could be observed in each group of the initial fabric and its variants. As the representative visual effect differences depicted in Figure 10, it was observed from each fabric series that higher densities tend to lead to a heavier drape and maintain their shape less. In contrast, fabrics with lower densities draped more loosely and had fewer folds or wrinkles.

Figure 10

Visual Effect Comparison of Drape in Low-Density versus High-Density Fabrics



Note. This figure demonstrates the visual impact of adjusting the CLO density value on the appearance of fabrics, focusing on comparisons within each of the seven selected virtual activewear fabrics. In the test, the density value was defined as low when the coefficient is lower than or equal to 10, and high when the coefficient is higher than or equal to 90.

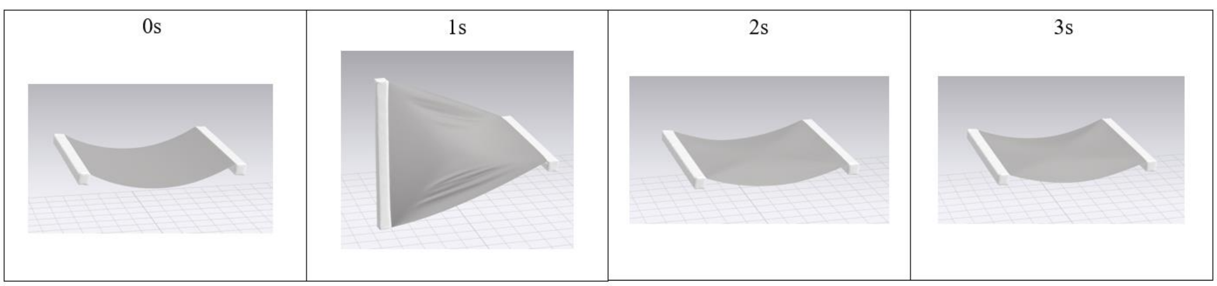
The same Cusick Drape Test was also conducted in the investigation of the impact of the *bending* property. The virtual fabrics were draped while varying the *Bending - Bias Right* and *Bending - Bias Left* parameters. The results of the test indicate that changes in bending properties had a more pronounced effect on the shape of the drape compared to density. With an increase in the bending value, the fabric was less susceptible to deformation, resulting in a flatter drape shape.

Regarding the investigation of *stretch and shear* properties' visual effect, based on the CLO guide (2023c), the *Stretch - Weft, Stretch - Warp,* and *Shear* intensities were used to indicate the level of resistance to elasticity in horizontal, vertical, and diagonal directions. To evaluate the deformation of a given fabric along a particular direction, the corresponding parameter for that direction was manipulated. By combining this with the independence of CLO virtual fabric parameters found in Section 4.2.1, it can be deduced that this approach permits the extrapolation of the fabric's deformation in other directions, based on the representative direction. This is due to the uniformity of the numerical conversion logic across all four parameters governing stretch and shear properties.

In the CLO simulation, the *Shear - Left* and *Shear - Right* were selected as representatives to explore the flexibility of different fabrics. The virtual fabric specimen was twisted using a two-stick model with a fabric piece hanging between them (see Figure 11). The animation lasted for three seconds, consisting of 90 frames. The two sticks reached the maximum point of motion at the first second (frame 30) and returned to their original position at the next second (frame 60). The rest of the time was static. The virtual fabric piece was 60 cm × 64 cm in size. This twisting action was performed on 35 fabrics (7 initial fabrics + 28 density variants). In each group of fabrics, as the value of *shear* increased, the fabric became stiffer. The specific visual changes included overall bounce state and wrinkle changes. When the shear value was small, indicating higher elasticity in the diagonal direction, the fabric appeared to bounce when it was twisted, with numerous wrinkles widely distributed on the fabric's surface. When the value was increased to a larger value, the bounce became less visible, and the number of wrinkles significantly reduced, concentrating mainly at the edges of the fabric.

Figure 11

Animation of Fabric Being Twisted



4.2.3 Implications for Phase 1

In this phase, the main finding was that within CLO, the parameters for *stretch and shear*, *bending* and *density* properties of virtual fabric operated independently. This knowledge informed the subsequent phase in which virtual fabric parameters were manipulated to investigate their visual impact, as the finding that each parameter served as an independent variable simplified the process of predicting and controlling the visual effects of virtual fabric alterations. Furthermore, it was observed that adjusting the coefficient of these parameters could significantly alter the visual dynamics of the virtual fabric, affecting its drape, stretch, shear, and twist behaviors. The independence and the noticeable visual impact of coefficient adjustments supported that these three parameters are feasible for visual assessments in the subsequent phases.

The range of 0 to 100 for parameters' coefficients was thoroughly explored in this phase, to ensure a comprehensive understanding of how these coefficient values influence the visual perception of clothing movement for the subsequent phases. The contrasting low and high values for these properties were set at 10 and 80, respectively, as previously detailed in Table 4 for Phase 1's visual stimuli construction. This range was chosen based on the substantial differences as observed through the corresponding values in common units. The exploration on the coefficient values also indicated that while the 0 to 100 coefficient range offered a broad spectrum for adjustment, it was an exaggerated span for replicating the properties of real fabrics in a virtual setting. Consequently, the virtual fabrics created with these parameter values underscored the synthetic nature of the simulation. It should be noted that the insights and observations made in this section were based on the subjective opinion of the current researcher and might not necessarily reflect objective facts or the views of other individuals or organizations. These preliminary insights and observations were intended to inform subsequent research phases and were subject to confirmation in the conclusions drawn from the analysis of the final phase.

4.3 Phase 1: Focus Group Study

The pilot focus group study in Phase 0A was instrumental in refining the focus group procedure methodology and providing experimental evidence that participants could articulate their visual perceptions of virtual fabric's clothing movement. Furthermore, the simulation tests in Phase 0B demonstrated that the contrasting values of virtual fabric parameters, *stretch and shear*, *bending* and *density* within CLO, significantly impacted the fabric appearance in motion. These tests also highlighted the independence of these parameters, allowing for their individual adjustment and analysis to determine their distinct impacts on clothing appearance.

Based on Phase 0A and 0B, the data analysis in Phase 1 aimed to delve deeper into the first two research questions (RQ1 and RQ2). RQ1 focused on validating the effect of three virtual fabric physical property attributes—*stretch and shear*, *bending*, and *density*—on consumers' perceptions of clothing movement. RQ2 aimed to identify the specific descriptors that consumers employ to articulate their observations of clothing movement within a 3D apparel motion simulation context. In Phase 1, the analysis began with the division of discussions into distinct content areas that each addressed specific topics. Once these content areas were identified, the next step involved coding each area, through which the analysis aimed to extract themes that reflected the participants' visual perceptions of clothing movement and insights regarding virtual fabric attributes.

4.3.1 Focus Group Results, Analysis and Discussions

The recordings of the focus group discussions were transcribed, allowing for subsequent categorization and data analysis. The transcriptions were divided into three primary content areas based on the pre-defined focus group procedure and discussion topics mentioned in Section 3.5.3. The three content areas are:

- Content Area 1: Discussing Mobility, Functionality, and Comfort Evaluation in Online Shopping;
- Content Area 2: Description of Visual and Tactile Sensations of Viewing Virtual Fabric;
- Content Area 3: Comments on Simulation and Display.

Content Area 2 was of particular interest, given its direct relation to the descriptions of the visual assessment of virtual fabrics. Each section was individually coded according to its specific content. Corresponding sections from two different discussions were reviewed and coded together, with attention to context.

During the transcribing process, the recorded contents and the transcript were read and re-read to familiarize researchers with the data, ensuring an overall understanding of the material. In general, the discussions revealed consistency in content, especially concerning the sensory experience of virtual fabrics, while some differences in repetitive content were observed. This indicated that the data collected in both discussions exhibited the quality of repeatability and variability, making it reasonable to combine the data for analysis.

4.3.1.1 Content Area 1. *Content Area 1* was titled *Discussing Mobility, Functionality, and Comfort Evaluation in Online Shopping*. To foster an engaging environment for discussion, two initial questions, similar to icebreakers yet with relevance to the study, were posed to the participants during the focus group sessions. Participants were first asked two questions:

1. In general, when you shop for activewear online, how do you evaluate the mobility, functionality, or comfort of the apparel you see? Do you rely on still images, videos, or a combination of both to evaluate these aspects?
2. Have you ever seen a simulated display of activewear instead of a real product while shopping online?

The first question aimed to elicit information related to the definition of comfort, helping the present researcher understand the composition of visual comfort and its distinction from general comfort. The responses to this question served as the primary data source of this content area. The second question was designed to evoke participants' understanding of 3D apparel simulation, encouraging them to draw from their memories when subsequently viewing the videos and participating in related discussions. While the responses to this question could offer valuable insights into participants' prior experiences with 3D simulation, this information was not directly pertinent to the primary analysis conducted in this study.

The categorization of data was oriented around the discussion content, with an emphasis on the visual channels through which participants perceived and evaluated the visual content related to activewear clothing movement. The findings have been summarized in Tables 11a and 11b below. During the discussions on evaluating activewear mobility, functionality, and comfort in fully online-based shopping scenarios, three distinct evaluation dimensions in fully online-based shopping scenarios emerged: *Fit*, *Fabric/Material/Texture/Hand Feel*, and *Functionality*.

Table 11a

Analysis of Content Area 1(Category 1: Fully Online-Based Evaluation)

Subcategory	Sub-subcategory	Representative Quote
Fit	Picture reviews	"Online I look a lot at the reviews because those when they have pictures, it's amazing. Because you know, you get a feel like how it's gonna fit you based on the pictures and the reviews."
	Product videos	"I think for me, one of the biggest things is videos are pretty important, but just visual in general, especially ... And so I got if I see a model wearing that size, that's what's really important to me, because then I know how it's gonna fit someone's body type."
		"Yeah, I agree with that. I think I see a lot of brands now moving towards showing different sizes for like showing a model for each size..."
	Product description	"I think size chart is a very important reference because I will look at like oversized t shirt or stuff so like if the size chart of the chest is like above 120 that that means the t-shirt will be somewhat oversize..."

Table 11a (continued)

Analysis of Content Area 1(Category 1: Fully Online-Based Evaluation)

Subcategory	Sub-subcategory	Representative Quote
Fabric/ material/ texture/ hand feel	Video/picture/social media reviews	"I will just go ahead and search the product in like YouTube or Tik Tok and see the review and if I and normally the people that are reviewing they will just explain what the fabric is like or how it is like if it is comfortable or not so yeah, and if I liked the review I'll buy the apparel."
		"I'm going off with like the social media aspect I think that I rely pretty heavily on consumer just like people that I follow who also wear that brand perhaps they're like athletes or something and so that makes me like trust the material more and trust the quality."
	Product close-ups	"I would actually prefer to have a hand feel of the fabric of the apparel. If it's possible if it's online then I probably will you know sometimes when you put your cursor on to that picture, it will enlarge it will zoom in that picture and you kind of can see the texture or the like knitting pattern of the of the fabric … I kind of imagined from that kind of knitting patterns to feel like to make to get a feel of what the fabric might be."
		"I feel like I would just because I could try to see the fabric like it might show more of the fabric and how it would really feel especially if they do like a close-up of the fabric and stuff like that."

Table 11a (continued)

Analysis of Content Area 1(Category 1: Fully Online-Based Evaluation)

Subcategory	Sub-subcategory	Representative Quote
	Product description	"I also see the garment tag and what fiber is made out of like I liked Tencel..." "For me material is also very important ... if it's made of cotton that appears to be more comfortable that I can daily wear but if it's made of nylon, I think it will be like more supportive and sometimes will more tight on your body so it does not appears to be as comfortable as the cotton one"
Functionality	Reviews	"I tend to look at the reviews a lot, especially talking about like functionality, especially for leggings. People usually leave reviews about like, do they ride down or do they ride up or like that kind of do they pill after washing or like that kind of stuff that I think most people want to know."
	Product description	"...like for functionality that product descriptions. I know like for Lululemon, specifically, they make different types of clothing for different sports. So I rely a lot on that as well."

Table 11b

Analysis of Content Area 1(Category 2: Evaluations with Physical Apparel)

Subcategory	Representative Quote
Try-on	" I think for me it's like I have to try before I buy like specially activewear." "Um when I go to shop in person I try to like try the garment first ..."

Fit. As detailed in Table 11a, the evaluation of *Fit* by participants was conducted through three primary channels: picture reviews, product videos, and product descriptions. One participant expressed appreciation for picture reviews by saying “when they (meaning online reviews) have pictures, it’s amazing,” underscoring the value of visual representation in assessing product fit. Similarly, another participant emphasized the overall importance of visuals, including videos, for gaining a comprehensive understanding of how a product might fit, as the participant said, “videos are pretty important, but just visual in general.” Further insights were gained from participants who valued seeing models with body shapes similar to their own and those who referred to size charts as part of their evaluation process, as indicated by the comments such as “I think I see a lot of brands now moving towards showing different sizes for like showing a model for each size” and “I think size chart is a very important reference”. From these discussions, *Fit* emerged as a concept of the spatial alignment between clothing and the human body, encompassing both shape and size considerations in an online shopping environment.

Fabric/Material/Texture/Hand Feel. The assessment of *Fabric/Material/Texture/Hand Feel* predominantly relied on three channels: video reviews, product close-ups, and descriptions. Participants expressed a notable correlation between the fabric and their tactile sensations, with an evident inclination to visually assess and anticipate the feel of fabrics in an online context. Highlighting the use of video platforms such as “YouTube and Tik Tok”, one participant said, “they (meaning videos) will just explain what the fabric is like or how it is like if it is comfortable or not so yeah, and if I liked the review I’ll buy the apparel”. This comment demonstrated the critical role of video reviews in providing detailed insights into fabric comfort. Further comments also underscored the significance of product close-ups in facilitating a mental simulation of fabric hand feel. As participants said:

> I would actually prefer to have a hand feel of the fabric of the apparel. If it’s possible. If it’s online then I probably will you know sometimes when you put your cursor on to that picture, it will enlarge it will zoom in that picture and you kind of can see the texture or the like knitting pattern of the fabric … I kind of imagined from that kind of knitting patterns to feel like to make to get a feel of what the fabric might be.

> "I feel like I would just because I could try to see the fabric like it might show more of the fabric and how it would really feel especially if they do like a close-up of the fabric and stuff like that."

Moreover, the mention of garment tags and fiber composition, as one participant pointed out, "I also see the garment tag and what fiber is made out of like I liked Tencel," highlighted the detailed product descriptions participants relied on in evaluating material.

Functionality. In contrast, *Functionality* pertained to the apparel's practical utility, with participants evaluating workout suitability and durability through product reviews and descriptions. For instance, as showcased in Table 11a, one participant emphasized the importance of reviews that discuss issues like " (the leggings) ride down or do they ride up or like that kind of do they pill after washing" . Product descriptions were also deemed crucial in assessing functionality, and one participant directly mentioned this point by saying "like for functionality that product descriptions. I know like for Lululemon, specifically, they make different types of clothing for different sports. So I rely a lot on that as well."

These findings around the category of *Fully Online-Based Evaluation* underscored the complex way participants assessed comfort by drawing from various information sources. This seems to contrast with scenarios where they can try on the clothes as the discussion indicated. As referenced in Table 11b, participants stressed the value of trying on actual garments for a direct and reliable understanding of comfort by saying "I think for me it's like I have to try before I buy like specially activewear" and "when I go to shop in person, I try to like try the garment first". These observations indicated that in an entirely online shopping environment, individual differences in trust and how receptive they are to various information sources can greatly affect how effectively these channels shape participants' perceptions of comfort. This perspective is important for the subsequent analysis in the next content area for understanding participants' interaction with visual and description content. The emphasis on the frequency of code mentioned became an important tool in this context. Despite the constraints of a smaller participant sample, using the frequency of specific codes is a feasible measure to determine the importance of these codes, as a high frequency suggests that a particular aspect of visual perception was mentioned often or agreed upon by multiple participants (Elliott, 2018). This commonality, even within a limited sample size, suggests a consensus on the visual perception components.

The data also revealed that distinct perception channels, as detailed in Table 11a and 11b, shaped the nuances of visual comfort among participant responses. Key visual channels associated with visually perceived comfort were *Fit - Product Videos* and *Fabric/Material/Texture/Hand Feel - Product Close-Ups*. Thus, the main dimensions of visual comfort focused on *Fit* and *Fabric/Material/Texture/Hand Feel*. These dimensions correlate with descriptors by Griffiths and Kulke (2002, p.254) that encompass "attributes describing movement (flowing, folds, cling, swing, bounce, drape)" and "material-associated attributes (shape retention, heavyweight, thickness)." The former requires video to depict fabric dynamics on the body, while the latter emphasizes specific fabric characteristics. However, responses in this content area did not clarify how functionality could be visually represented in clothing displays, even though it's essential in evaluating garment comfort. This omission pointed to the need for further analysis in the next content area. The current findings enhanced the overall understanding of visual comfort, with subsequent discussions anticipated to provide additional depth and clarity for the ongoing data analysis.

4.3.1.2 Content Area 2: Analysis of Descriptions Concerning the Look and Feel of the Fabrics. *Content Area 2* was titled *Description of Visual and Tactile Sensations of Viewing Virtual Fabric*. The data examined in Content Area 2 originated from the primary discussions, during which participants viewed 3D apparel simulations in the set sequence. The data categorization for *Content Area 2* was guided by both the focus group procedure and the discussion content. The organization initially followed the chronological sequence of the conversation and the viewing order of videos showcasing different fabric variants. Sub-categories were then established based on the content, whether it described the recently viewed fabric or drew comparisons among fabrics. A detailed outline for this content area can be found in Table 12. It should be noted that the conversations following the viewing of the F1 fabric video didn't include comparisons, since this segment only showcased a single virtual fabric. However, beginning with the F2 fabric video, from the F2 fabric video onwards, participants naturally began drawing comparisons using the previously viewed virtual fabrics as references, while comparative language that did not specifically reference another fabric was categorized under the content describing the recently viewed fabric.

Table 12

Outline for categorizing Content Area 2

Categories	Sub-categories
Discussion after watching F1 video	Description of how F1 looks and feels
	Description of how F2 looks and feels
Discussion after watching F2 video	Comparison between F1 and F2
	Description of how F3 looks and feels
Discussion after watching F3 video	Comparison between F1, F2 and F3
	Description of how F4 looks and feels
Discussion after watching F4 video	Comparison between F1, F2, F3 and F4
	Description of how F5 looks and feels
Discussion after watching F5 video	Comparison between F1, F2, F3, F4 and F5
	Description of how F6 looks and feels
Discussion after watching F6 video	Comparison between F1, F2, F3, F4, F5 and F6

Based on the guidelines delineated in Table 12, both transcripts and video recordings were meticulously reviewed multiple times to identify codes and subcodes within each sub-category. From the analysis of *descriptions on how the fabrics F1 to F6 look and feel*, evaluative codes highlighting visual-tactile properties emerged. Additionally, clear expressions of visual comfort preference for certain fabrics were also evident. The encoding process differentiated between movement-involved (MI) and non-movement-involved (NMI) comments. MI comments, which included descriptions of the simulated fabric behavior or movement, had a stronger connection to clothing movement compared to NMI comments, making it crucial to distill MI comments. Furthermore, by examining participants' preferences, insights were gained into how predefined characteristics of these virtual fabrics with exceptionally high or low values impact visual perception. The MI and NMI comments related to visual-tactile properties of fabrics

F1 to F6, and along with visual comfort preferences between fabrics, formed the foundation for a deeper exploration of *descriptions on how the fabrics F1 to F6 look and feel*.

Following the initial identification and categorization of responses, as well as the differentiation between MI and NMI comments, an in-depth analysis of descriptions concerning the look and feel of fabrics F1 to F6 was conducted. Given the expansive length of the results, these results were outlined in Appendix A, complemented by representative quotes highlighting the observable features of each virtual fabric. The frequency of visual-tactile property responses was counted based on frequency of being mentioned. As previously mentioned, such repetitions reflected not only the consistency in individual participants' perceptions but also the consensus among participants within the current focus groups. Upon meticulous review of the codes, five themes emerged as dimensions significantly impacting the visual comfort of virtual fabrics. They are *visually perceived flexibility*, *drapability*, *supportability*, *weight*, and *thickness*. For the purposes of this analysis, these dimensions were compactly referenced as *flexibility*, *drapability*, *supportability*, *weight*, and *thickness*. These dimensions, as shown in Appendix A, were derived from the codes that represent straightforward, individual visual-tactile attributes. These codes were further classified as either MI or NMI, with MI comments capturing descriptions of the simulated fabric's behavior or movement.

To elucidate each dimension, the codes, sub-codes, and representative quotes as detailed in Appendix A were reorganized into long tables presented in Appendix B, where the codes under each sub-theme were arranged in descending order, based on the frequency of the codes from highest at the top to lowest at the bottom. This organization aided in identifying the characteristic fabric movements that influenced the visual-tactile dimension's intensity. As a result, the relationship between the descriptions of visible virtual fabric movements (namely the MI comments) and evaluations pertaining to the five dimensions of visual comfort became clear in this restructured data. Additionally, by identifying shared characteristics in the codes that describe visual-tactile sensation, the overlapping relationship between the five dimensions was analyzed. The detailed analysis of these five dimensions unfolded as follows.

Flexibility. The theme of *flexibility* prominently surfaced in most of the extracted codes and quotes, indicating its critical role in visual comfort and its prevalence in discussions. *Flexibility* denoted the visually perceived ability of a fabric to deform, further categorized into three sub-themes: *resilience*, *stretchability*, and *conformability*. Each relates to how a fabric was perceived to react to stress. However, distinguishing these sub-themes was challenging in MI comments. For instance, participants stated that a fabric "snaps back pretty easily", which could be seen as demonstrating both *resilience* (its ability to promptly return to form) and *stretchability* (how much it can stretch while still reverting). Participants' observations about a fabric's natural movement, such as it is "moving with your body, folding and then unfolding as you stand straight", seem to blur the lines between perceptions of *flexibility* and *conformability*. Such overlaps could arise from the difficulty in discerning the specific forces on the fabrics, especially evident in activewear simulations.

A prominent pattern also surfaced among participants: they consistently equated the notion of *flexibility* with the observable act of the fabric being "pulled", irrespective of whether the fabric was undergoing stretching or twisting. While participants recognized and commented on visible outcomes of these interactions, such as the fabric's "bouncing" or "wrinkling", they found it harder to pinpoint the underlying forces that produce these reactions. Consequently, due to these interpretive challenges and the resulting overlap in descriptors, the term *flexibility* has evolved. Instead of denoting a single specific fabric behavior, it represented a broad spectrum of fabric responses — also a term that participants leaned on heavily throughout the discussion. Given the extensive discussion content centered on *flexibility*, in the following analysis narrative, this theme was subdivided into *high flexibility* and *low flexibility* as delineated in the subthemes in Table 13.

- *High Flexibility* - *Bouncing*: Table 13 presents two key fabric movements that emerged as indicators of high flexibility as perceived by participants: *bouncing* and *moving with the body/lay on the body*. Within the *bouncing* discussion, the descriptors of *bouncing back strongly* ("the bounce back seemed like very strong and easy to recover") or *bouncing back easily* ("it seems like it snaps back pretty easy") or *bouncing a lot* ("it pulls a lot more and it kind of like bounces") were perceived as markers of significant fabric flexibility as directly mentioned in the representative comments. Notably, these comments were exclusively associated with the simulated fabric pulling test video, suggesting that this pulling action was perceived to be the most illustrative in visually conveying a fabric's flexibility, compared to shearing and twisting actions.

- *High Flexibility – Moving with the Body/Lay on the Body*: The second indicator *moving with the body/lay on the body* was particularly noted during discussions on the simulated activewear video. This observation indicated that participants felt that a fabric simulating a highly flexible appearance should adeptly conform to variations in human body movements. As delineated in Table 13, this movement was categorized into three types, each emphasizing a fabric's *resilience*, *stretchability*, and *conformability*. Participants commented, "it kind of goes with the movement of the body and then takes its shape back" and "if you move left, the fabric will move left, but then kind of go back to being like straight" when they focused on the leg opening of the simulated loose jumpsuit, which depicted the fabric's resilience. Meanwhile, comments such as "it's able to stretch in a lot of different ways" and "how they lay on the body" emphasized how the participants perceived fabric's stretchability when they described the jumpsuit's appearance around the torso of the body. Lastly, participants' observations like "it just goes with your body, it folds with the body and then unfolds once you stand straight…and it just looks like naturally like it's naturally moving" conveyed the fabric's conformability. Similar to the *bouncing* description, the idea of a fabric *moving with the body or laying on the body* also underscored the perceived fabric's ability to retain its shape. These quotes accentuated that participants perceived the fabric's capability to move congruently with the wearer, stretch in harmony with body contours, and naturally adjust to body dynamics. This indicated that the fabric was not perceived to display an entirely fluid behavior, spotlighting its enhanced flexibility and adaptability.

- *Low Flexibility – Static*: The comments indicated that virtual fabrics characterized by *low flexibility* tended to be associated with more distinct MI descriptions than those exhibiting *high flexibility*. As delineated in Table 13, fabrics displaying behaviors such as *holding the shape with little bounces* ("It didn't really bounce back or anything. It kind of just held its own shape.") and *sticking to the body/ not conforming to the body* ("It sticks to the body. It's got some sort of like static like it's just attracted to the body but like in like the wrong places.") as described by participants were indicative of perceptions of *low flexibility*. The associated representative quotes consistently conveyed a sense of stillness perceived by participants, implying that the fabric and the human body seem to operate independently, each exhibiting its own unique motion, from participants' perspective.

Table 13

Analysis of Flexibility

Subthemes	Codes	Subcodes	Representative quotes
High flexibility	Bouncing	Bouncing back strongly	"But it looks like it had good recovery from the first video, like the bounce back seemed like very strong and easy to recover." "...fabric almost touching on the ground but it has the resistance to go back and bounce off. So it makes me to think about it is elastic. elastic and stretch. Stretchability."
		Bouncing back easily	"When I was watching the videos of it being pulled apart, I think it seemed like ... good retention ... Because it seems like it snaps back pretty easy, which is something that you would want in like athletic wear."
		Bouncing a lot	"It's super flexible, especially in like the first like, um, just fabric videos that it pulls a lot more and it kind of like, like bounces."
	Moving with the body/ laying on the body	Moving with the body and then regain the shape (resilience-emphasized)	"I like that, like it kind of goes with the movement of the body and then takes its shape back." "This one has a little bit more of a structure where like, if you move left, the fabric will move left, but then kind of go back to being like straight."

Table 13 (continued)

Analysis of Flexibility

Subthemes	Codes	Subcodes	Representative quotes
		Lay on the body (stretchability-emphasized)	"...it's able to stretch in a lot of different ways. And like it lays on the body pretty well" "I definitely think they're very similar in stretch and like how they lay on the body."
		Creases/ wrinkles/ folds moving with the body (conformability-emphasized)	"The creases to move with her body. It's not super stiff, you can see a lot of movement, even in the tighter fitting one. Like, as she moves like back and forth, you see wrinkles and it's just like it moves with the body really well." "It just like it goes with your body, it folds with the body and then like unfolds once you like stand straight and it just looks like naturally like it's naturally moving"
Low flexibility	Static	Holding the shape with little bounces	"Like it didn't really bounce back or anything. It kind of just held its own shape." "I think this one has the least elasticity because as the strength the pulling video it Yeah. As you can see like in the corner like when wit come back it doesn't bounce back."
		Sticking to the body/ not conforming to the body	"I feel like the way like it's it sticks to the body it's got some sort of like static like it's just attracted to the body but like in like the wrong places." "Just like looking closely at the way that it like bunches up at her hips. It did not seem like this fabric had nearly as much stretch in it as the other ones did. "

To sum up the analysis on *flexibility*, this attribute was indicated to play a pivotal role in the perception of visual comfort in virtual fabrics. Specifically, the virtual fabric behaviors characterized as *bouncing* and *moving with or laying on the body* served as critical indicators for *high flexibility*. These behaviors suggested the virtual fabric's adaptability and responsiveness to body movement. In contrast, fabrics with *low flexibility* exhibited a more static or unyielding behavior.

Drapability. The theme of *drapability* emerged as the second dimension, primarily occurring within the context of loose activewear videos. As depicted in Table 14, one participant noted, "You can tell how thin and loose the fabric is by how easily it moves around and flows around the leg". Another participant supported this observation by describing the fabric as "very flowy". These comments described fabrics considered to have high drapability. A deeper layer of *high drapability* was added by another participant, highlighting the fabric's bounce-back quality. When watching the pulling video of simulated fabric, they remarked, "It looks like it bounces back more than the ones we've seen... it's still fairly drapey". This observation suggested that the fabric was perceived to have a bounce-back attribute, yet still retained its drapable quality. Conversely, a participant highlighted a distinction, pointing out a fabric that was "not made to be loose and flowy", signifying that they perceived it to have low drapability. As depicted in Table 14, *flowing* and *bouncing* were key indicators of *high drapability*, with *flowing* representing a fabric's capacity to smoothly contour over underlying shapes perceived by participants. In contrast, fabrics perceived as having *low drapability* typically lacked this flowing characteristic, as the comment mentioned, "it's not made to be loose and flowy." Participants perceived a more static visual impression in this situation.

Table 14

Analysis of "Drapability"

Subthemes	Codes	Representative quotes
High drapability	Flowing	"You can tell like how like thin and like loose the fabric is just by like around the leg how easily it just kind of moves around and flows" "I think that this one is very flowy."
	Bouncing	"It looks like it bounces back more than the ones we've seen, like that kind of jiggle at the end. It feels like it, it bounces back more, I think it might be like, in my brain ... it's still fairly drapey."
Low drapability	Not flowing	"...it could be and it's not made to be loose and flowy"

In comparison to *flexibility*, discussions around *drapability* were less frequent, and the associated MI comments were more general, lacking detailed insights into the dynamic behavior of fabrics. This difference could stem from the limited visual stimuli showcasing fabric draping situations, suggesting that while both attributes—*flexibility* and *drapability*—are vital, *flexibility* could gain more immediate attention during fabric evaluations.

Supportability. The third salient theme identified is *supportability*, intrinsically related to the comment "supportive." This theme encompassed attributes such as the fabric's compressibility and stiffness from the discussion. *Supportability* was mainly discussed by participants within the context of simulated activewear videos, indicating its association with the virtual fabric's capacity to offer support and uphold structure during the avatar's movements. As delineated in Table 15, one participant pointed out, "I almost think that fabric four is just a little bit stiffer because this one just seems to wobble more", and another noted that it "has good compression in terms of maintaining the shape", reflecting the association formerly discussed. The theme was further underscored by comments highlighting the fabric's close resemblance to swimwear fabric due to its adherence to the body without noticeable gapping or draping. The relevant comment said, “It almost felt like a swimwear fabric to me in a sense because of the way that it like almost stuck to the body and the tighter one and it didn’t have a lot of gapping or draping or anything.” Some participants also paid attention to the visual cues of the fabric: draglines and wrinkles were observed in some fabrics, indicating varying levels of stretch and compression, as one participant mentioned, “I noticed like wrinkles at the hip... it wasn’t the stretch but more the lack of compression”. Moreover, another participant perceived a fabric that “seems like it could be somewhat compressive but still move with the body” especially when compared to other fabrics that lacked any draglines. These discussions highlighted the nuanced interplay between a fabric’s stiffness, compression, and its capacity to align seamlessly with body movements, all encapsulated within the concept of *supportability*.

Table 15

Analysis of Supportability

Subthemes	Codes	Representative quotes
High supportability	Bouncing/Wobbling	"I almost think that fabric four is just a little bit stiffer because this one just seems to like wobble more or the other one like bounces more if that makes sense."
	Static	"...but I think it has good compression in terms of maintaining the shape" "It almost felt like a swimwear fabric to me in a sense because of the way that it like almost stuck to the body and the tighter one and it didn't have a lot of gapping or draping or anything..."
	Few creases	"It doesn't really. Like there's no draglines or like, you know." "And I liked that this one seems like it could be somewhat compressive but still move with the body. Um, because it still has this draglines compared to like fabric to that didn't have any kind of draglines in it. "
Low supportability	Wrinkling	"I noticed like wrinkles at the hip as well. And I did think that I learned a lot more like what be said about the tighter video but to me the wrinkling wasn't really like this is just how I interpreted it wasn't the stretch but more the lack of compression. So like it is stretchy enough to go over the person's body but maybe it's too much of a looser stretch to the point that it's creating those wrinkles. Because when you have like a garment that has compression, it's not conforming to the to the wrinkles in the body but rather like smashing it so it's all like the one flat skin piece. I don't know how to describe it. But I felt like this was like a looser kind of stretch to where it was like creating those draglines."
	Gapping	"... this one can like it's not very clear to see your body shape." "It kind of looks like in the back there, there might be like some, like gapping between her back and the fabric."

Despite extensive discussions on *supportability* as detailed in Appendix B, MI comments were notably sparse, as indicated from Table 15. In contrast, NMI comments regularly incorporated terms such as “stiff-soft,” “tight-loose,” “compressive-not compressive,” and “supportive-not supportive”, providing insight into the visual interpretations of *supportability*. The representative comments were “it has a little bit of stiffness”, and “it looks really compressive or it could be and it’s not made to be loose and flowy.” This is similar to the *drapability* discourse discussed previously, the delineation of *supportability* tended to revolve around more overarching evaluations rather than detailed observations specific to distinct fabric video scenes. The limited use of movement-related terms for *supportability* might be attributed to the inherent static nature of fabric supportability, as shown by codes like *static* and *few creases*.

Additionally, when analyzing the codes from the MI comments related to *supportability* and *flexibility* as presented in Tables 13 and 15, clear contrasts emerged. Fabrics in this study perceived as high in *flexibility* were also described by participants as exhibiting noticeable bouncing, an optimal number of wrinkles or creases, and a lower level of static nature. Comments like “it bounces back easily”, “it moves with the body and then goes back to its shape”, and “the creases to move with her body…It’s not super stiff, you can see a lot of movement” showed that these fabrics were perceived to adapt well to movement. On the other hand, fabric perceived as high in *supportability* were described as demonstrating appropriate bouncing, minimal or absent wrinkles or creases, and a strong static nature, meaning fabrics seen as supportive were perceived with a more controlled bounce and keep their shape. Some participants even said they felt that such fabrics were “like swimwear” because of how closely they fit. Taken together, these comments implied that fabrics displaying a balanced flexibility were perceived as offering optimal support, while those lacking in *supportability* tend to have pronounced “wrinkling” and “gapping”, suggesting a less effective body fit and a more relaxed appearance.

Weight. The fourth salient theme that emerged is *weight*. Discussions around this theme were particularly prominent during participants’ watching the simulated fabric pulling video and the loose activewear video. As delineated in Table 16, in the pulling video, the visual perception of a fabric’s weight was revealed by the fabric *dropping downward* (“it was like a midweight fabric because of the way it kind of like is held down by gravity") and *bouncing irregularly* ("when you pull back it like bounces but it like doesn't like bounce up and down. It kind of goes down lower. So for me this looks heavy") after recovery from stretching. These comments suggested that they perceived a *weighted recovery*, where the fabric returned to its original shape in a way that conveyed a sense of heaviness due to its mass and density. Furthermore, in the loose activewear video, participants particularly noticed a lagging response in fabric movement corresponding to changes in the avatar's motion. Observations such as "when it's flowing at the bottom of the legs, it almost looks like it's going and then the rest of the fabric kind of catches up with it" highlighted the code of *weighted draping*. The inertia-driven folding was observed when the hem of the simulated bodysuit following the avatar's movement.

Table 16

Analysis of Weight

Subthemes	Codes	Subcodes	Representative quotes
Heavyweight	Weighted recovery	Dropping downward	"...it actually seemed like maybe it was like a midweight fabric because of the way it kind of like is held down by gravity." "Where it shows this fabric kind of like just like, drop at the very end. Because it shows at least I think that the fabric is more densely knit like that" "I…I felt that this fabric is the heaviest fabric because this fabric was almost touching on the ground when you're relaxing the fabric test."
		Bouncing irregularly	"When we were looking at the first clip the fabric to me looked heavy like it it's like heavy and elastic because like when you pull back it like doesn't like bounce up and down. It kind of goes down lower. " "it's like pretty dense because when we did the pulling like when it when you pulled it ... like it like goes down like the first drop is like heavier and then it has two sudden like bounces after it."
	Weighted draping	Delayed folding	"So like when she's moving, it would like fold and then it would take some time to fold back." "I would also say that fabric is a bit heavier. Just because of the way when it's flowing like at the bottom of the legs, like it almost looks like it's like going and then the rest of the fabric kind of catches up with it if that makes sense. Kind of like if you're spinning like long skirt and that like keeps going."

Interestingly, there was an absence of MI comments on lightweight properties. This could imply that clear visual signs of the virtual fabric variants being lightweight might be harder to discern or perhaps less striking to viewers. Alternatively, these cues might not have left as strong an impression, resulting in fewer mentions during discussions.

Thickness. The fifth primary theme that emerged is *thickness*, mainly referring to the discussions surrounding loose activewear videos. As detailed in Table 17, characteristics indicating a fabric's perceived thinness encompassed attributes such as *easy to wrinkle/fold/crease*, *flowing*, and *bouncing*. Participant comments supported these associations. For instance, one participant observed, "I feel this one might be thinner, given its propensity to wrinkle and fold." This connection between thinness and ease of wrinkling was further emphasized by another participant pointing out the fabric's tendency to fold, especially around the crotch area. The relevant quote mentioned, "in the crotch area I was giving like a little bit of a camel toes I feel like it's like…easy to fold." Observations about how the fabric contoured around the body further informed perceptions of thickness, with comments such as, "its thin nature around the leg influences how it folds and flows." Another participant's comment linking bounce to thinness, "Fabric three appears thinner because it bounces more", further underscored this relationship.

Table 17

Analysis of Thickness

Subthemes	Codes	Representative quotes
Thin	Easy to wrinkle/fold /crease	"I feel this one might be thinner, as it's easier to wrinkle and fold." "And then like in the crotch area I was giving like a little bit of a camel toes I feel like it's like a very like easy to fold."
	Flowing	"Because of how like thin like I specifically look like around the leg and like to see how it folds and like flows."
	Bouncing	"Fabric three to me is much more thinner because it bounces more."

Interestingly, these visual cues — wrinkling, flowing, and bouncing — were previously associated with *drapability* and *supportability* as delineated in Table 14 and Table 15. In those contexts, *wrinkles* signified lower supportability from participants' perspective, and *flowing* and *bouncing* indicated higher drapability. This overlapping identification could suggest a pattern among participants' perception: a virtual fabric perceived visually as highly drapable and less supportive tended to be interpreted as thin. Consequently, the perceived *thickness* of the virtual fabric variants seemed related to its visually observable behaviors, specifically those associated with *drapability* and *supportability*.

However, it is noteworthy that this study found a lack of content directly addressing fabric *thickness* perceptions. This absence could potentially be attributed to the visual stimuli used in this study predominantly showcasing thin fabrics, thus limiting contrasting visuals to stimulate discussions around *thickness*. Alternatively, participants might have subconsciously evaluated thickness when discussing other fabric attributes such as *weight*, *drapability*, and *supportability*, rather than explicitly mentioning it. Interestingly, no specific description about the thickness of the F1 variant emerged. This could be due to the other distinctive attributes of F1 fabrics overshadowing its thickness in the discussion.

In addition to the five primary dimensions of visual comfort identified in the study of virtual fabrics — *flexibility*, *drapability*, *supportability*, *weight*, and *thickness* — two other aspects were also observed: *comfortability* and *possible fabric type*. Both elements symbolized complex semantic or cognitive vocabularies associated with fabric properties, diverging from the singular visual-tactile characteristics of the earlier mentioned dimensions. The detailed analysis of these two themes was delineated as follows.

Comfortability. The analysis revealed that *comfortability* was perceived to be closely related to the simulated tight activewear's capacity to retain its form without substantial structural movements, like seam displacement, as illustrated in Table 18. When viewing the tight jumpsuit video, one participant observed, "but the way that it moves here seems really nicely like it stretches enough for it to not feel that seam go all the way around you if that makes sense." This emphasis on *holding its form* suggested that *high comfortability* might align with high levels of *supportability* in tight activewear from participants' perspective. This link could imply that the visually perceived fabric's ability to provide support and maintain structure during the avatar's movements also contributed to the visual perception of comfort.

Conversely, visual cues of fabric *wrinkling* could imply *low comfortability*, which correlated with the earlier findings that such fabric movements denoted *low supportability*. The quotes such as "until like after I was like down here like the wrinkle on the back of her leg. It's very small. But for me, this seems not comfortable" describing the tight jumpsuit supported this perspective. It appeared that when participants viewing tight-fitting wear, the perceived *supportability* might heavily influence the visual comfort perception, given the similar visual stimuli triggering these perceptions.

Table 18

Analysis of Comfortability

Subthemes	Codes	Representative quotes
Comfortable	Holding its form	"(Before this sentence, the participant was saying the other fabric was not comfortable) but the way that it moves here seems really nicely like it stretches enough for it to not feel that seam go all the way around you if that makes sense."
Not comfortable	Wrinkling	"Until like after I was like down here like the wrinkle on the back of her leg. It's very small. But for me, this seems not comfortable"

Possible Fabric Type. Regarding the theme of *possible fabric type*, while discussions covered all fabrics under consideration, few MI contents provided specific visual cues of fabric movements to aid clothing movement related analysis. This scarcity could be because the identification of fabric type required a comprehensive understanding, leading participants to rarely link it with specific visual scenes. As noted in Table 19, fabric movements of *bouncing back easily* and *smooth transitioning* have been correlated with fabric *flexibility*, hinting at synthetic activewear materials. The related comment mentioned, "because it seems like it snaps back pretty easy, which is something that you would want in like athletic wear." In contrast, the actions of *hanging and dropping* may conjure notions of densely knit fabrics, as one participant commented, "it made me think that maybe had bigger spaces between the knit like stitches or something like that" when watching the pulling video. Notably, these characterizations echoed prior content pertaining to *heavyweight* and *high flexibility* attributes.

Table 19

Analysis of Possible Fabric Type

Subthemes	Codes	Representative quotes
Activewear fabric/good for activewear	Bouncing back easily	"Because it seems like it snaps back pretty easy, which is something that you would want in like athletic wear."
synthetic/blend fabric	Smooth transitioning	"I think the way that the drapes ... like the folds happened when the fabric stripping in this video kind of makes me think ... and this is like a long shot but kind of makes you can guess to synthetic fabric. Just because how they slide out and how they don't really retain that draped look. Also how the the folds are like really thin and like close together."
knit jersey	Hanging and dropping	"Compared to the other one where when it did that pull, it would just kind of like hang in there a little bit and like just go down. Um, it made me think that maybe had bigger spaces between the knit like stitches or something like that."

Interestingly, although the dimensions of visual comfort mentioned above were consistently discussed across all fabric variants, descriptions pertaining to surface features were uniquely associated with the F1 analysis. Yet, since these descriptions were absent from the MI contents, they were not incorporated into the analysis here.

Summary of Key Dimensions. The detailed analysis on MI comments above led to the findings of the five key dimensions — *flexibility*, *drapability*, *supportability*, *weight*, and *thickness* — influencing the visual comfort perception of virtual fabrics through interconnected relationships. In the context of 3D apparel simulation in motion, perceived *flexibility* emerged as the dominant theme due to the large number of relevant codes and quotes extracted, intertwined with other dimensions like perceived *supportability* that impact how virtual fabric variants appeared to move, adapt, and responded to the viewer's perception. Perceived *Drapability* and *supportability* factored into this by influencing how the virtual fabric flowed and maintained its structure respectively, potentially affecting perceived *thickness*. In addition, perceived *weight* was determined by the virtual fabric's movement responses, while *thickness* interplayed with *drapability* and *supportability*. Finally, the themes of *comfortability* and *possible fabric type* weaved together multiple dimensions, indicating that comfort perception might be connected with factors like *supportability* in tight activewear displaying scenes. These dynamics suggested that viewer perception of virtual fabrics hinged on a complex interplay of these key dimensions.

4.3.1.3 Content Area 2: Comparisons of contrasting virtual fabric pairs. To convey a more comprehensive understanding of these five key dimensions of fabric perception, it is important to recognize the significance of fabric movements that indicate a virtual fabric's visual-tactile attributes, as evidenced by the responses. These movements presented an intricate web of complexity due to their varying type, intensity, and form. This divergence made it challenging to interpret the perception of virtual fabrics, as each movement could signify diverse facets of these dimensions as indicated in the previous analysis. To refine this complexity, the subsequent analysis integrated the preset feature properties of six different virtual fabrics—the extremes in CLO *stretch and shear*, *bending*, and *density* properties. The comparisons of these contrasting virtual fabric pairs were detailed in Appendix C due to the extensive volume of the data. This analysis aimed to illuminate the relationship between these dimensions and the preset properties of the virtual fabrics, thereby enhancing the understanding of fabric visual perception and pinpointing the movements most strongly associated by participants with these objective parameters.

F1 and F5 (Contrasting Pair of Stretch and Shear Properties) . As delineated in Table 4 in Section 3.5.1, F1 is a highly elastic virtual fabric, with values of 10 in all virtual coefficients pertaining to stretch and shear in both weft and warp directions. Conversely, F5 has low elasticity, with coefficient values of 80 in the same categories. The comparative comments on these fabrics uncovered the perceptual implications stemming from variations in the virtual fabric's *stretch and shear*. The comments with the highest frequency encompassed descriptors of F1, *good stretchability*, *flexible*, and *soft*. Such descriptors indicated that participants perceived a high degree of *flexibility* and a slightly compromised *supportability* in F1. Notably, descriptions of F1 substantially align with the MI comments pertaining to *high flexibility*. The fabric's movements were perceived to *bounce back easily*, *bounce back strongly*, and *bounce a lot* in the simulated pulling video, which illuminated its flexibility. Observations from the activewear simulations emphasized perceptions of F1's harmony with body movements, implying its prime suitability for activewear applications, as perceived by participants.

In contrast, descriptions of F5's visual attributes resonated with its *low flexibility*. Visual perceptions of F5 notably included descriptors such as *wrinkly/crinkly/creasy*, suggesting low resilience. As participants described, its compromised elasticity made it visibly prone to permanent deformations like wrinkles. Furthermore, F5 was predominantly discerned as a non-durable, lower-quality material, eliciting descriptions like *non-woven/medical fabric/cheap fabric*. In discussions, it ranked as the least comfortable.

The comparative analysis of F1 and F5 accentuated participants' visual perception of *flexibility* when *stretch and shear* attributes were modulated. Distinct fabric movements were evident in simulated fabric test and activewear videos due to the contrasting values of *stretch and shear* properties. In pulling test simulations, a fabric's *bouncing* frequency and behavior emerged as salient indicators of its *flexibility* as perceived by participants. High frequency *bouncing* and the capacity to *bounce back* were indicative of superior resilience and elasticity, while minimal bounce suggested *low flexibility* to participants. Moreover, the presence of pronounced *wrinkly/crinkly/creasy* attributes during body movements could signal *low flexibility*. Concurrently, alterations in *stretch and shear* properties subtly influenced fabric *supportability* perceptions. Highly flexible fabrics elicited *soft* descriptors. For fabrics with *low flexibility*, as evidenced in F5's analysis, the *stiffness* perceived was less about rigid texture but rather about its non-extensibility. This interpretation was corroborated by comments noting F5's apparent thinness. Interestingly, virtual fabrics' parameters that reduced flexibility also seemed to make F5 appear notably thin.

F2 and F4 (Contrasting Pair of Bending Properties). F2 and F4 made another contrasting combination for comparative analysis. F4 was configured with high bendability settings across weft, warp, and bias directions, evidenced by values of 10 in all relevant digital fabric properties. Conversely, F2 was configured as markedly unbendable, illustrated by values of 80 in its weft and warp bending properties. Theoretically, within the context of 3D apparel simulations, this setup suggested that F2 would have higher supportability and less flexibility compared to F4.

Comments corroborate that F4 was perceived as having *low supportability*, with descriptors such as *slightly stiff*, *possible compressive*, and *lack comparison*. Most observations related to F4's *low supportability* were intrinsically linked to the avatar's movements which show gapping between the garment and body, and the fabric's wrinkled appearance. For example, participants mentioned, "it like bunches up at her hips. It did not seem like this fabric had nearly as much stretch in it as the other ones did", and "it still has these draglines compared to other fabric that didn't have any kind of draglines in it." Comments related to F2's simulated representation also closely aligned with its preset characteristics. Descriptors such as *compressive/supportive*, *not wrinkly*, and *not moving with the body* underlined that activewear garments simulated from F2 maintained their shape, adhering closely to the avatar's form, presenting a virtually unwrinkled texture.

The comparison between F2 and F4 also implied that the manipulation of bending values not only manifested in the perceived *supportability* but also introduced other notable visual characteristics due to the adjustment of these bending properties. F4's evaluation placed significant emphasis on its attributes like *good stretchability*, *thinness*, and *heavy/dense*. This was mainly perceived through the simulated fabric pulling test – almost touching the ground then sharply rebounding – which suggested high flexibility. Participants commented, "the fabric almost touching on the ground but it has the resistance to go back and bounce off. So it makes me think about it is elastic. elastic and stretch. Stretchability." However, this behavior imparted an illusion of weight or density as well. The fabric's propensity to *wrinkle* and *flow* also gave it a perceived thinness, drawing parallels with the visual characteristics of F5. In contrast, F2 discussions emphasized its *compressive/supportive* nature and *slow recovery*, indicating its *low flexibility* but *high supportability*. This perceived rigidity and compression contributed to the perception of heaviness. Overall, F4's qualities of stretchability and thinness contributed to its comfort and appeal to participants, whereas F2, despite being supportive, was perceived as less comfortable due to its visual thickness and implied heaviness. This comparison highlighted how the manipulation of bending properties influenced both virtual fabrics' functional attributes and how they were perceived visually.

F3 and F6 (Contrasting Pair of Density). F3 and F6 were also compared due to their clear distinction in density coefficient values. F3 was configured to have a low density, represented by a density coefficient value of 10, while F6 was configured for high density, characterized by values of 80. Theoretically, such configurations should result in distinct visual perceptions of weight. However, instead of being identified as lightweight, F3 was frequently described as "thin" in discussions. This observation, combined with the limited mentions of MI comments in relation to lightness throughout entire discussions, raised the possibility that the terms "lightness" and "thinness" may be perceived interchangeably by participants. Evidence for this was the descriptions of F3, such as *bouncing a lot*, which appeared to be referencing *weight* (gravity and mass comparison) rather than mere *thickness*. The predilection to perceive "light" but articulate it as "thin" may arise from perceptual, linguistic, and experiential interplay. Given that touch and sight are primary in fabric interactions, the tangible and visible attributes of a fabric, such as its thinness, could become more salient than its weight, especially in a visual assessment that lacks physical contact. The term "thin" could encompass density and texture nuances, not just thickness, making it more contextually apt than "light." This perception that F3 was thin engendered discussions on its flexibility and comfort, with many noting its flowy appearance, which reinforced its thinness. Comparatively, both F3 and F4 were deemed suitable as activewear fabrics, though F3 appeared less supportive than F4. It's inferred that perceived thinness and flexibility might overshadow other properties to influence perceptions of supportability.

Conversely, discussions surrounding F6's perceived weight were more mixed. Some found it light, while others leaned towards it being heavy. This divergence in views may arise from the observation mentioned previously, that participants might conflate "light" with "thin." Furthermore, descriptions focusing on fabric movement tended to support the perception of it being heavier. Notably, participants perceived that F6’s flow differed starkly from F3’s lightsome flow, aligning more with the *weighted draping* description provided in Table 16. However, these weight-related observations seemed secondary to the fabric’s *flexibility*, as whether participants perceived F6 as light or heavy, a consensus on its comfort emerged. Overall, F6’s visual weightiness was deemed acceptable, which was a surprising outcome given the high-density configuration upon which it was based.

These contrasting virtual fabric pairs are systematically organized in Appendix C, highlighting:

- Overall impressions derived from the descriptions of *possible fabric type*;
- Dominant visual-tactile attributes (denoted by high frequency codes);
- Primary dimensions of visual comfort (themes underpinned by high frequency codes);
- Descriptive keywords concerning fabric movement (namely MI comments that elucidate visual-tactile attributes);
- Degrees of user liking derived from the *emotional expression* comments in Appendix A.

4.3.1.4 Content Area 2: Comprehensive Analysis of Fabric Descriptions and Comparison Results. The comparison results in Section 4.3.1.2 complemented the previous analysis of the five key dimensions of virtual fabrics’ visual comfort in Section 4.3.1.3. The comparative analysis elucidated that *flexibility* was an important factor influencing the visual perception of fabric comfort because F1, F3, F4, and F6, which were generally perceived as comfortable, all exhibited *high flexibility* traits. Conversely, F2 and F5, which have been associated with discomfort, exhibited *low flexibility*. Another discerning factor is *supportability*. Fabrics of *high supportability*, namely F2 and F5, were observed to have less visual deformation and appeared stiffer, affecting their perceived adaptability to human movement, as noted by participants.

Based on these results, it would seem that *drapability* and fabric *thickness* nuances contributed to the overall visual comfort but played secondary roles. Interestingly, perceived fabric thickness appeared predominantly contingent on other dimensions of visual comfort. As evidence, descriptors of *thinness* as listed in Table 17 correlated with those of *flexibility* and *supportability*. In addition, in the comparison analysis involving F3, it was further substantiated that perceived fabric *thinness* was principally perceived from visible attributes like creases, wrinkles, and folds in the activewear videos, and there were significant similarities in the visual cues associated with perceived *drapability* and *thinness*: both presented as nuanced, partial appearances of folds or wrinkles. Such observations suggested that the established dimensions of visual comfort—*flexibility*, *supportability* and *drapability*—might encompass the concept of thinness, especially when conveying fabric movement visually. Moreover, *drapability* could represent apparel functionality, serving as an additional axis of visual comfort. For instance, F3, which showcased pronounced drapability in comparison to F1 and F4, was commented for the use of high impact activewear—differentiating it from the latter fabrics. This relationship suggested that fabrics considered highly flexible and low in support, when coupled with pronounced *drapability*, might be suited for high impact activewear apparel.

The analysis of contrasting fabric pairs, particularly through their movement descriptors, elucidated the potential changes in fabric characteristics when parameters were modulated. This analysis provided clarity on the inherent magnitude of intensity within these descriptors, solidifying their appropriateness for subsequent quantitative evaluations. As shown in the comparison between F1 and F5, and between F2 and F4, movement descriptors of *bouncing* and *compatibility with body movement* served as key visual comfort indicators when participants discussed fabric test simulation and activewear simulation contexts. Fabrics exhibiting consistent movement with the body, regardless of fit, showed comfort, while static or creased appearances suggested the opposite. Notably, these movements majorly dictated perceived *flexibility*. Furthermore, the movement comparison between F2 and F4 implied that observable features indicating *supportability* include “wrinkling” and “gapping”. Low-support fabrics might display more wrinkles and visible gaps, implying low adherence to the body, while the opposite suggested high support. Evaluating the movements of F3 and F6 revealed that a fabric’s drapability was majorly manifested through its *flowing* movement. More specifically, this movement was observed in the *flowing* folds presented at the garment’s downward openings, such as the leg openings. In full simulated activewear video clips, these specific visual cues may appear sporadic or fleeting to viewers. This transitory nature might explain why *drapability* has less impact on overall comfort assessments compared to *flexibility* and *supportability*.

A noteworthy parallel between the movement descriptors of F4 and F6 indicated that fabric *weight* perception in the pulling test video was primarily influenced by the strength of the bouncing movement. Stronger bouncing suggested heaviness, while easy bouncing hinted at lightness. Yet, this perception contrasted sharply with the significant virtual density differences assigned to F3 and F6. This disparity suggested that, similar to fabric *thickness*, the visual perception of simulated fabric *weight* diverged considerably from its tactile counterpart. This visual perception may be swayed by the ambiance engendered by the combined visual cues of *flexibility* and *supportability*.

Additionally, the data drawn from the sub-categories, *comparison between different fabrics*, which was previously outlined for categorizing *Content Area 2* in Table 9, was comprehensively presented in Appendix D, offering a holistic comparison of the six virtual fabrics. The feedback from participants played a pivotal role in determining fabric preferences based on the dimensions of visual comfort, leading to the final selection of fabrics demonstrating superior and inferior visual comfort.

The data showed that F1, F3, F4, and F6 shared comparable visual attributes in terms of *flexibility*, *supportability*, *drapability*, and overall comfort. This resemblance was particularly pronounced for F1, F3, and F4. Interestingly, F4's attributes seemed to align more closely with F6 than they did with F1 or F3, given its description as slightly stiffer and heavier than the latter two, mirroring the characteristics associated with F6.

It is worth noting that participants consistently described F3 as thinner, lighter and even stretchier than F1, indicating a more lightsome drape for F3. As per the insights in the *best & worst comfort* segment in Appendix C, F1, F4, and F6 were predominantly identified as top-tier fabrics suited for activewear. While F3 appeared ideal for everyday apparel, it was fundamentally viewed as comfortable. Moreover, the good drape quality of both F1 and F6 was recurrently mentioned as a factor contributing to their perceived functionality and comfort in activewear, reinforcing previous analysis centered around drapability.

4.3.1.5 Content Area 3. *Content Area 3* was titled *Comments on Simulation and Display*. It delved into data collected post-viewing of all the simulated videos. Participants shared insights predominantly concerning the simulated visual presentation and its inferred relation to apparel mobility and comfort. This feedback session was instrumental in enriching this content area, specifically offering a comprehensive discussion on recommendations and remarks concerning 3D apparel simulation and visualization. While viewing and discussing the virtual fabric variations, additional comments pertaining to the simulated visual display also surfaced. These scattered inputs were integrated into the remaining sections of *Content Area 3*. The primary objective of this analysis was to gauge the efficacy of the current simulation videos in conveying visual comfort and the descriptive movements characteristic of the virtual fabric. This understanding served as a foundational guide for enhancing the quality and accuracy of simulated videos in subsequent phases.

For a more granular view, Appendix E houses detailed quotes from participants, while Tables 20a and 20b categorized the feedback into positive and negative comments, featuring representative quotes regarding the simulation and display. These two tables further break down the data by associating comments with specific simulated video types and pinpoint the exact opinions expressed.

Table 20a

Analysis of Content Area 3: Positive Comments on Simulation and Display

Video Type	Codes	Representative quotes
Fabric test videos	Understanding Fabric properties	"I think the pulling video mostly helped me to identify the differences between different fibers ... I can clearly from the videos to see how stretchy the fabric is."
Activewear videos	Understanding fabric properties	"...but the looser outfit definitely told me a lot." "... but the looser garment I think shows a lot more just based off of what I would like being able to see on a body helps a ton. And when it's so much easier to tell. "
	Avatar movement simulation appreciated	"I thought the dance thing that she was doing was such a creative way to show different motions a lot of like, if I ever see anything like usually it's like a video and rather than like an digitally simulated thing, but it's always with active wear like running or like the weight like this. And the motions I think that that the Avatar was doing I think it it showcases a lot of ways that your body moves while you're exercising that aren't shown as much. That is very interesting. It shows kind of all your different muscle groups being used."

Table 20b

Analysis of Content Area 3: Negative Comments on Simulation and Display

Video Type	Codes	Representative quotes
Fabric test videos	Correlation challenge	"So somehow for me I'm kind of having a hard time to correlate with the fabric test and the avatar movements."

Table 20b (continued)

Analysis of Content Area 3: Negative Comments on Simulation and Display

Video Type	Codes	Representative quotes
	Understanding fabric properties	"I think that was it gave me more of a sense of the structure if that makes sense and the way that it stretches because especially with the videos you can't really tell how the stretches as…"
	Fabric appearance concerns	"For some reason with it looking kind of like a twill weave from the side. Also, was it off for me like when it turns you can like see that it's actually not but I don't know from like the side view. Especially with the stretching one It only looks like it's kind of got those, like diagonal stripes on it. Just looks like weird"
	Scale	"Oh, and for these tests video, like the fabric test videos, I would prefer if there is like something to like to compare with a scale or like a scale bar to show because, like for the stretch ability test, if there's nothing to compare with, it's hard to imagine which one is extend better. Let's say like between fabric one and three, they... when you looking at them that together. And as they're so fast, it's so hard to tell which one is more elastic."
		"Or maybe how big this swatch is, because I think it can tell you a lot about the weight, if that makes sense."
		"I also think a print could help me understand like the scale of it. Because if this fabric was like the swatch was two by two versus 24 by 24 I think that the fabric will feel a lot different if it had those properties, if that makes sense…"

Table 20b (continued)

Analysis of Content Area 3: Negative Comments on Simulation and Display

Video Type	Codes	Representative quotes
	Incorporating real-life elements	"Many fabric were offered in this website called Fabric Wholesale Direct. And they have their like swatch like videos, but it's like a guy like pulling it with his hands…so maybe if it was like instead of the two bars maybe if it was like like virtual like hands or something maybe that would be nice."
Activewear videos	Range of movement	"I have one comment about the tight fitting clothing simulation on the model, I would like to see if a bigger movement can be done for the model like bending all over to like, bending over to reach the ground." "When it comes to the dancing I felt like the movements were especially if this is being used in athletic wear, I felt the movements in that dance specifically were a little tame…I want to know if the fabric is going to get more see through when I bend over that kind of stuff. " "I think it'd be interesting to see how, like the fabric fit if it was just like a pair of leggings or something and they bent over and how that recovery would happen. If it would like stay in the same place or been pulled down. I think that'd be interesting to see." "We need a squat."

Table 20b (continued)

Analysis of Content Area 3: Negative Comments on Simulation and Display

Video Type	Codes	Representative quotes
	Fabric appearance concerns	"…My brain is like tricking me into thinking that they're all like woven or knitted, even though they may not be in terms of when you're going to replicate it into the real world. So it would be nice to be able to see, like close ups of the fabric you're trying to replicate."
		"That and also how thin it is because for me if I do activewear, I would not like it to be see-through…So that like with the squat test or like the bending over test just to see if you know you have to wear specific colors underneath the garment to make sure that you're not like exposing yourself that'd be nice too."
		"I think the biggest thing that I'm missing with these is how the opacity works…Like it would be a very helpful video to to have like that tight fitting garment."
		"Just because on the tight one, like on a real person, you'd be able to see like dimples in the skin or like just the texture of the skin kind of and I feel like on an avatar doesn't have those like really specific like folds and wrinkles and things like that. So I don't know I feel like personally I wouldn't trust what it looks like tight on an avatar."
	Incorporating real-life elements	"I think it could be helpful to put like a pattern on it to see how the pattern stretches and if that would be like distorted or not."
	Understanding fabric properties	"yeah, no, I definitely agree with the tighter outfit. I if you took that video and the video from before, I probably wouldn't be able to tell you the difference from them."
		"So, like especially for the tight fitting garments. I just have trouble figuring out anything out of it"

Table 20b (continued)

Analysis of Content Area 3: Negative Comments on Simulation and Display

Video Type	Codes	Representative quotes
	Detailed Visual Representation	"Like if we have a little close up or a small video of like, the fabric itself, it would be like better to judge."
General	Fabric appearance concerns	"And also like the color of the fabric I feel like would really affect how it looks on a person."
	Understanding fabric properties	"I am personally having a hard time with like, without knowing the fiber content or like anything that I'm having a hard time making like a decision of whether or not I would think it'd be comfortable…" "I still I think I personally as a consumer, just have a hard time with the visuals like this… It wouldn't do too much for me."

The feedback derived from the fabric and activewear videos was multifaceted, touching on aspects from the videos' informative value to their visual accuracy. One key theme emerged from the category *Positive Comments on Simulation and Display* was *understanding fabric properties* through fabric test videos. As indicated by the corresponding quotes in Table 20a, participants particularly appreciated the pulling video by commenting, "the pulling video mostly helped me identify the differences between different fibers…I can clearly from the videos to see how stretchy the fabric is." This indicated that the participant felt the video facilitated an enhanced understanding of the differences between various fibers, emphasizing its ability to clearly demonstrate fabric stretchability. Another positive dimension was the insights obtained from the loose activewear videos. The loose jumpsuit, as opposed to the tight ones, seemed to be more informative, enabling participants to glean more about fabric texture and properties. The representative comments were "the looser outfit definitely told me a lot", and "the one that it's loose, you can tell I think the texture of the fabric more maybe". Additionally, the avatar movement simulation was appreciated, as participants commented "the dancing thing she was doing was such a creative way to show different motions a lot". The decision to incorporate dance-like movements was viewed as innovative, presenting a wide range of body movements, which the participants believed was instrumental in showcasing how fabrics would behave in real-world scenarios, saying "it showcases a lot of ways that your body moves while you're exercising that aren't shown as much. That is very interesting. It shows kind of all your different muscle groups being used." These participant observations suggested that aspects of the visual stimuli were organized effectively to elicit rich responses.

However, a significant concern from participants was the challenge in correlating fabric tests with avatar movements, suggesting a potential disconnect in representing consistency across various mediums. The comments such as "having a hard time to correlate with the fabric test and the avatar movements" supported this perspective. Diving deeper into the fabric test videos, several areas of potential improvement emerged. Participants felt some videos did not adequately depict fabric stretchability, as indicated by the comment saying, "specially with the videos you can't really tell how the stretches".

There were also issues with the appearance of the fabric in videos. One participant mentioned, "from like the side view, especially with the stretching one. It only looks like it's kind of got those, like diagonal stripes on it. Just looks like weird". Another recurrent suggestion from participants was the incorporation of a scale or a point of comparison, which could offer enhanced clarity, especially concerning fabric elasticity. Participants mentioned, "if there's nothing to compare with, it's hard to imagine which one is extend better", and "maybe making like the garments a solid color and then the like swatch a print or something like that might help" to express this perspective. To provide a more tactile sense of the fabric, some participants also suggested adding more real-world elements, such as virtual hands ("maybe if it was like virtual like hands or something maybe that would be nice").

Concerns extended to the activewear videos as well. Participants expressed a need for the avatar to engage in more pronounced movements, particularly in tighter outfits, to better demonstrate fabric stretchability and overall performance. Examples of the representative quotes included "bigger movement can be done for the model like bending all over to like, bending over to reach the ground", and "we need a squat". The visual representation of fabrics also surfaced as a concern. As delineated in Table 20b, in the representative quotes of *detailed visual representation* and *fabric appearance concerns*, participants directly voiced a desire for a clearer differentiation in fabric appearances, with an emphasis on showcasing fabric opacity during stretches ("I think the biggest thing that I'm missing with these is how the opacity works…Like it would be a very helpful video to have like that tight fitting garment."). They also pointed to a need for more detailed visuals such as close-ups of fabrics, to allow for a more informed judgment ("if we have like a little close up or like a small video of like, the fabric itself, it would be like better to judge.").

On a broader note, color was highlighted as a significant determinant in fabric perception, as indicated by the representative comments "with the squat test or like the bending over test to see if you have to wear specific colors underneath the garment to make sure that you're not like exposing yourself ," and "I think it could be helpful to put like a pattern on it to see how the pattern stretches and if that would be like distorted or not". Participants also commented "I am personally having a hard time with like, without knowing the fiber content or like anything that I'm having a hard time making like a decision of whether or not I would think it'd be comfortable." This suggested that without a more comprehensive understanding of fabric properties, such as fiber content, participants felt they couldn't conclusively judge the fabric's comfort based solely on the visuals provided.

In conclusion, while the simulations and videos provided valuable insights, there were clear opportunities for improvement. Taking the feedback into account could greatly enhance the clarity and effectiveness of visual representations in upcoming iterations. Among the five display types, the loose activewear video stood out prominently. This could be attributed to the avatar's movement combined with the added freedom that the fabric has due to the looser fit, allowing for a more vivid representation of the virtual fabric's behavior. The fabric pulling test video also received positive feedback, as it effectively demonstrated the fabric's dynamics when stretched, aiding in assessing its flexibility. Considering these points, it would be advisable to showcase close-ups within the loose activewear video. This approach not only incorporated real-life elements, such as the simulated human body, but also accentuated the dynamic details of the fabric, offering viewers a comprehensive and engaging visual experience.

4.3.2 Initial Findings for Phase 2

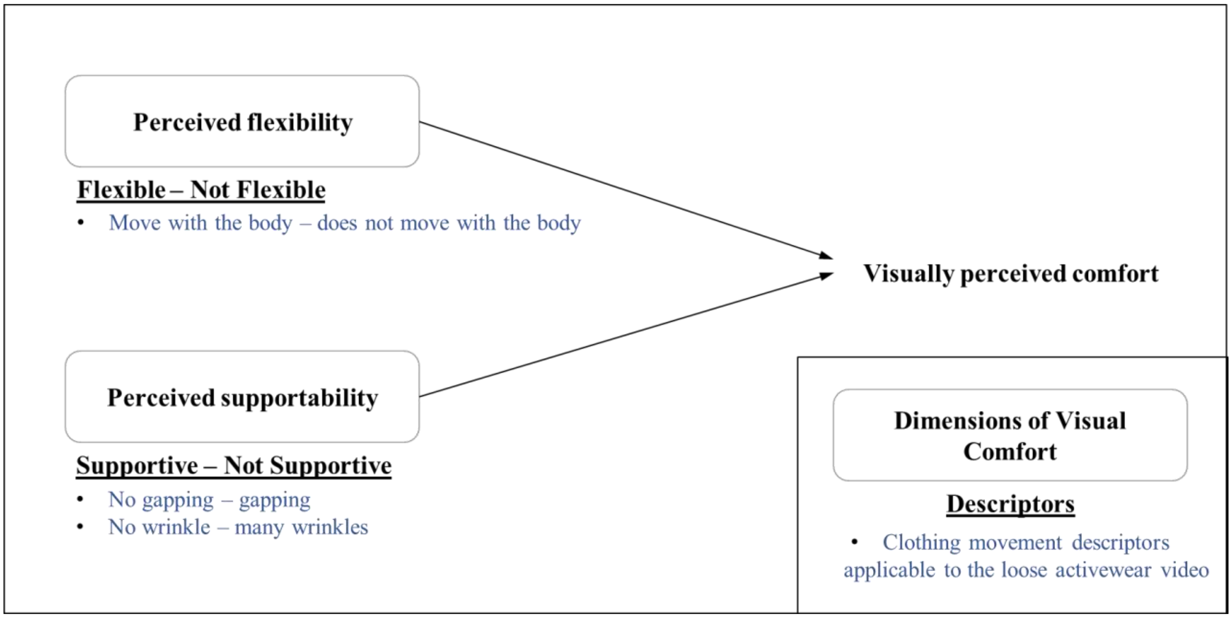
In Phase 1, the aim was to gain a holistic understanding of the various aspects of the clothing movement as perceived by U.S. consumers of women's activewear when viewing simulated apparel in motion. Insights were primarily drawn from two focus group discussions, which aimed to extract the descriptive words that reflect the perceptions of U.S. consumers of women's activewear regarding simulated clothing dynamics as visual stimuli.

While all three content areas received thorough analysis, *Content Area 2* was the main source for extracting descriptive words related to clothing movement, directly addressing the research question RQ2. The in-depth analysis within *Content Area 2* revealed multiple themes underscoring the dimensions of visual comfort. The analysis focusing on the descriptions of how the six fabrics feel and appear, along with the comparison between contrasting pairs of virtual fabrics, identified *flexibility* and *supportability* as the primary dimensions influencing perceptions of visual comfort. The analysis highlighted several aspects indicating that *high flexibility* combined with *low supportability* generally translated to a perception of comfort, whereas *low flexibility* paired with *high supportability* tended to lead to a perception of discomfort. In addition, the term *light/heavy drape* represented the visual perception of drape quality, becoming particularly relevant when considering the functionality of activewear apparel. However, the data did not show a direct correlation between drape perception and functionality. Both extremely light and heavy drapes did not necessarily translate to suitability for either impact activities. Identifying an optimal drape range and its relationship to functionality requires further study. However, due to its intricate nature which could potentially complicate the analysis of visual comfort, an exploration into the *light/heavy drape* dimension was not undertaken in the subsequent phase of the current study.

From this analysis, responses representing clothing movement descriptors corresponding to these visual comfort dimensions were also identified. Distinct sets of descriptors were deemed relevant for both loose activewear videos and fabric pulling test videos. These findings were encapsulated in Figures 12 (a) and 12(b). The two figures presented a systematic progression of visually perceived comfort, influenced by clothing movement within either 3D apparel or fabric simulations. These insights significantly informed the design of subsequent research phases. Specifically, the acquired knowledge informed the construction of visual stimuli to be deployed and the choice of clothing movement descriptors to be employed. Drawing from the analysis of *Content Area 3* as additional references, the subsequent phase adopted the proposed descriptors as illustrated when displaying videos of simulated loose activewear, as shown in Figure 12(a). Moreover, close-up videos of simulated loose activewear were also utilized for deeper investigation.

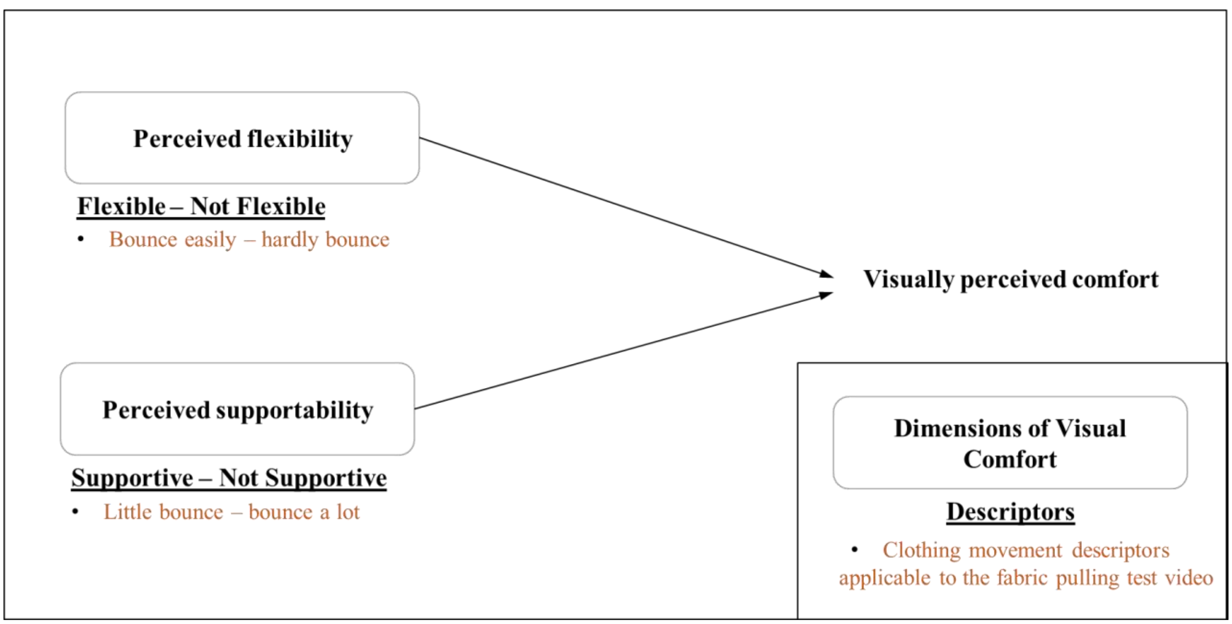
Figure 12 (a)

Proposed Dimensions of Visual Comfort and Their Corresponding Descriptors of Clothing Movement (in Simulated Loose Activewear Video)



(b)

Proposed Dimensions of Visual Comfort and Their Corresponding Descriptors of Clothing Movement (in Simulated Fabric Pulling Test Video)



4.4 Phase 2: Online Survey using MaxDiff Conjoint Approach

Phase 2 expanded on the previous phase by implementing a MaxDiff conjoint survey. This phase aimed at elucidating the general visual perception trends within the context of 3D clothing movement simulations in the present research, to interpret *flexible*, *supportive*, and *comfortable* as key descriptors to establish links between visual comfort perception, 3D simulated clothing movement and virtual fabric factors. The data processing and analysis integrated Rstudio (2023.09.1 Build 494 with R 4.3.2) and JMP Pro 17.0.0 (622753), with additional support from Origin (2023b 64-bit SR1 10.0.5.157 Learning Edition) for graphical representation of data.

The analysis unfolded in three distinct approaches. Initially, MaxDiff analysis was conducted using JMP at the profile level (referring to virtual fabric variants derived from conjoint virtual fabric parameters) to determine the visual rankings of simulated fabric videos concerning their perceived flexibility, supportability, and comfortability. The MaxDiff analysis was also extended to the attribute level (directly involving virtual fabric parameters) to understand how *stretch and shear*, *bending*, and *density* of the CLO virtual fabrics individually influence these three aspects of visual perception, meaning perceived flexibility (FL), supportability (SU), and comfortability (CO). Secondly, regression analysis was employed to examine the presence of significant correlations among the three perceptions' evaluation (MaxDiff scores), and to construct the relationships between the three virtual fabric parameters and the evaluations of these perceptions (utility scores). Thirdly, the study categorized all eight virtual fabric variants using K-means clustering, based on their influence on these three visual perceptions (utility scores) from the MaxDiff analysis at the profile level. This step aimed to identify potential visual perceptual patterns of perceived FL, SU, and CO for each virtual fabric variant within each comparison in the survey questions. It is important to note that the virtual fabric parameters included in the aforementioned analysis—*stretch and shear*, *bending*, and *density*—are all ordinal variables with only two values, low=10 and high=80. Lastly, the study evaluated interobserver and intraobserver variability by including the in-lab participant group as a comparative cohort, to discuss its impact on the interpretation of the main findings. This multi-faceted approach provided a comprehensive analysis of visual perception patterns in an online survey environment.

4.4.1 MaxDiff Analysis

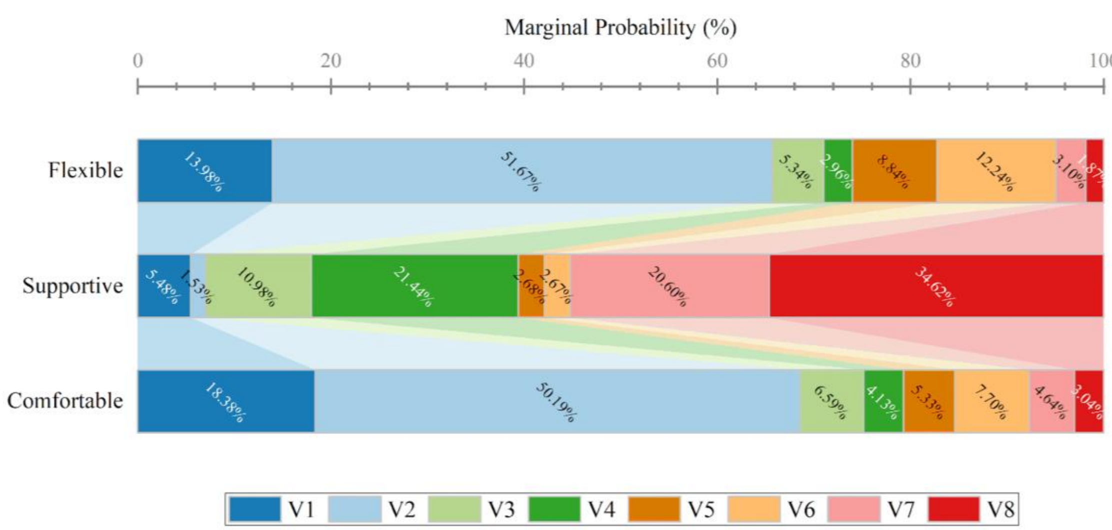
The MaxDiff analysis was performed in JMP by using "Analyze – Consumer Research – MaxDiff". As noted in the JMP help documentation, particularly considering the smaller-than-usual sample size and limited diversity of respondents in the present study, Firth Bias-Adjusted Estimates were applied to the computed marginal utility scores for yielding aggregate-level insights (JMP help – MaxDiff, 2023). The hierarchy Bayesian estimation was also used in the MaxDiff model for designating a large number of Bayesian iterations (=20000) for a more accurate estimate. To conduct the MaxDiff analysis at the profile level, the data column representing virtual fabric video items (namely virtual fabric variants) was the only one selected as profile effects in the model. The visual evaluation scores pertaining to the virtual fabrics' FL, SU, and CO were quantified using a three-tier scoring system: -1, 0, and 1. These scores represent the least, neutral, and most perceived levels in each aspect, respectively. Each aspect of visual perception was then calculated using these encoded scores.

The result revealed a ranking of perceived FL in simulated fabric videos, ranging from the most to least flexible as V2, V1, V6, V5, V3, V7, V4, V8. V2, characterized by low *stretch and shear*, low *bending*, and high *density*, was the clear leader in FL with a marginal probability of 0.517. Subsequent rankings and probabilities were as follows: V1 (0.140), V6 (0.122), V5 (0.088), V3 (0.053), V7 (0.031), V4 (0.030), and V8 (0.019). Conversely, in perceived SU, the videos ranked from the most to least supportive as V8, V4, V7, V3, V1, V5, V6, V2, with marginal probabilities of 0.346, 0.214, 0.206, 0.110, 0.055, 0.07, 0.027, and 0.015, respectively. This demonstrates a notable contrast in the visual perceptions of FL and SU, with four fabrics (V2, V1, V6, V5) ranking high in FL and low in SU, and the reverse being true for the remaining (V3, V7, V4, V8). The observed differences can be linked to the varying *bending* values. Specifically, fabrics V2, V1, V6, and V5 exhibited lower *bending* values, while fabrics V3, V7, V4, and V8 demonstrated higher *bending* values.

Regarding perceived CO, the fabrics were ranked from the most to least comfortable as V2, V1, V6, V3, V5, V7, V4, V8, with V2 again leading in CO (marginal probability 0.502). The following values were observed: V1 (0.184), V6 (0.077), V3 (0.0660), V5 (0.053), V7 (0.046), V4 (0.041), V8 (0.030). Figure 13 summarizes these comparative results, suggesting a general trend where higher FL corresponds to greater CO. Conversely, reduced SU tends to align with lower CO. Notably, V2 and V6 align with this pattern, ranking high in FL (1st and 3rd, respectively), low in SU (8th and 7th), and high in CO (1st and 3rd). Their visual similarity is marked by numerous fine folds and a smooth, uninterrupted silhouette in the simulated jumpsuit, attributed to their low *bending* and high *density*. In contrast, V4, V7, and V8, with V8 being the most supportive yet least flexible and comfortable, lack a contour-following silhouette in the simulated jumpsuit.

Figure 13

Comparative Summary of Virtual Fabrics' Influence on Perceptions of Flexibility, Supportability, and Comfortability



Note. The marginal probability values are presented in percentage format.

The behavior of virtual fabrics V1, V3, and V5 slightly deviates from the general trend observed. V1, ranking second in FL, does not correspondingly place low in SU (ranking 5th) but maintains a high level of CO (also 2nd). This pattern suggests that among the displayed fabric items, when fabric deformation is observed, as indicated by lower *bending* values, a lower *density* value might better represent supportability. V3, differentiated from V1 only in terms of *bending*, exhibits higher *bending* values that reduce virtual fabric deformation during motion. Despite being equipped with high *bending* values, V3's low *stretch and shear* values, coupled with its low *density*, do not render it as supportive as its counterparts. Nonetheless, V3 still achieves a respectable balance, ranking fourth in both SU and CO. V5, characterized by low *bending* and *density* values but high in *stretch and shear* properties, ranks as moderately flexible (4th), low in supportability (6th), and slightly uncomfortable (5th). This attribute mix results in a virtual fabric that appears highly deformable yet lacks sufficient supportability to be perceived as comfortable. Both V5 and V3, in striking a balance across the three visual perceptions of clothing movement, emerge as the most neutral among the eight virtual fabrics. The dynamic demonstrations of these virtual fabrics' visual ranking in Figures14 (a), 14(b), and 14(c) vividly showcase their respective influences on the perceptions of flexibility, supportability, and comfortability.

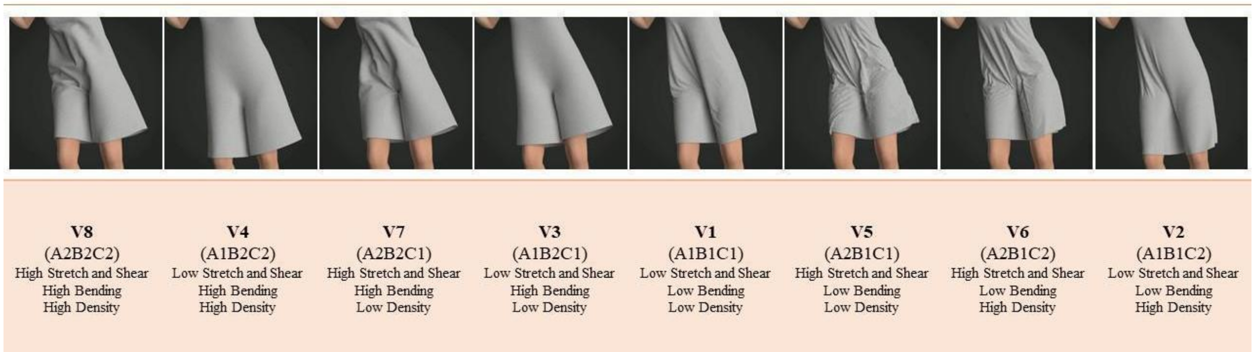
Figure 14 (a)

Visual Ranking of Virtual Fabrics Based on Perceived Flexibility (Most to Least)

Figure 14 (continued)

(b)

Visual Ranking of Virtual Fabrics Based on Perceived Supportability (Most to Least)



(c)

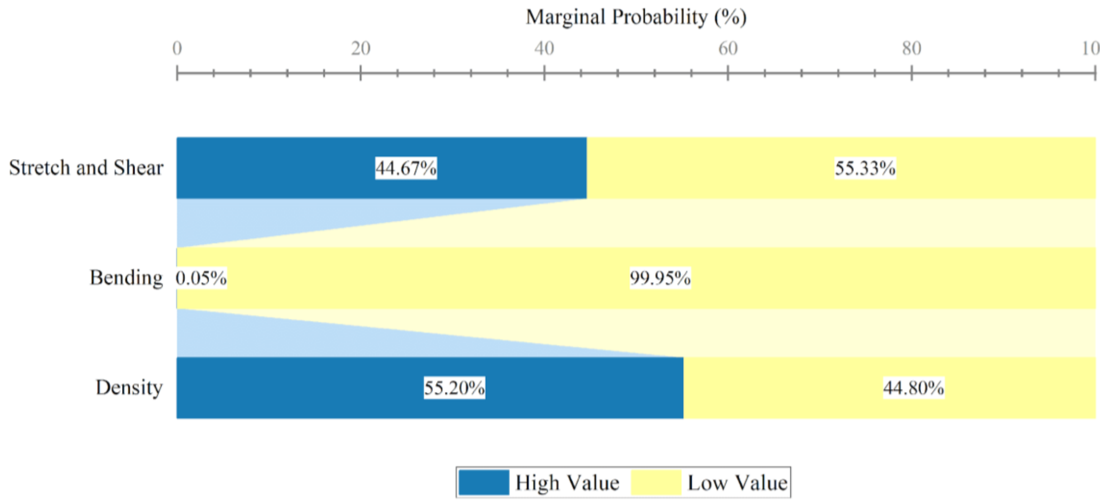
Visual Ranking of Virtual Fabrics Based on Perceived Comfortability (Most to Least)

Note. Figures 14(a), 14(b), and 14(c) are derived from videos created by the author to visually represent the rankings for an enriched data analysis comprehension. The video corresponding to Figure 14(a) is available at https://rb.gy/yocjgw, that for Figure 14(b) at https://rb.gy/asbnoa, and for Figure 14(c) at https://rb.gy/mk849e.

To delve deeper into how each virtual fabric parameter was visually evaluated, an additional MaxDiff analysis was carried out, comparing settings of low and high parameter values. This attribute-level MaxDiff analysis involved selecting three columns that represent the attributes (meaning *stretch and shear*, *bending*, and *density*) of each virtual fabric video item as profile effects, while keeping all other model settings consistent with the previous analysis. Figures 15 (a), 15(b), and 15(c) display the marginal probability values to contrast the low and high values of parameters impacting FL, SU, and CO, respectively. The larger the difference in marginal probability between two attributes (low and high), the more influential the attribute with the higher marginal probability is considered.

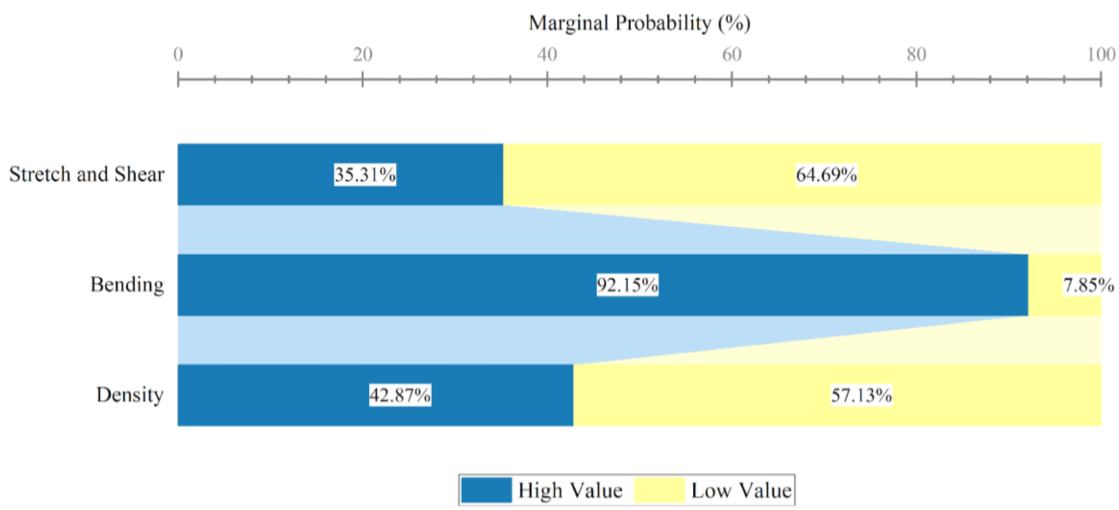
Figure 15 (a)

Comparative Summary of Virtual Fabric Parameters' Influence on Perceptions of Flexibility



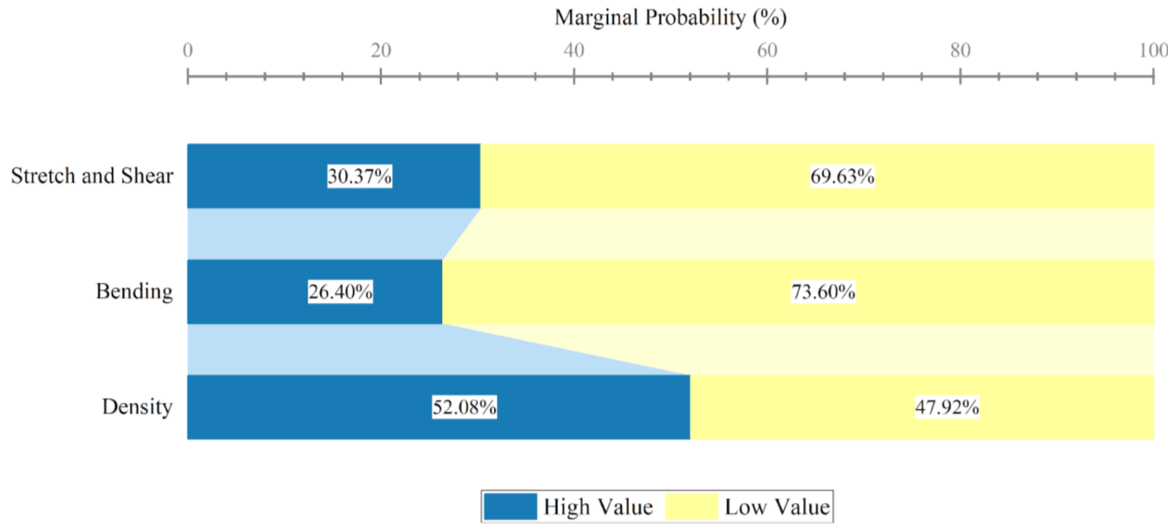
(b)

Comparative Summary of Virtual Fabric Parameters' Influence on Perceptions of Supportability



(c)

Comparative Summary of Virtual Fabric Parameters' Influence on Perceptions of Comfortability



Note. The marginal probability values are presented in percentage format.

Figure 15(a) indicates that for visual perception of FL, low *bending* properties are highly preferred, as evidenced by a significant marginal probability of 0.100, correlating to the virtual fabrics' visual ranking in FL. Conversely, low *stretch and shear* and high *density*, with marginal probabilities of 0.553 and 0.552 respectively, are somewhat influential but not decisive. Figure 15(b) shows that high *bending* values (marginal probability 0.922) considerably enhance SU perception. Low values in *stretch and shear* (marginal probability 0.647) and low *density* (marginal probability 0.571) also contribute to this perception, although less significantly. Figure 15(c) illustrates that both low *bending* values and low *stretch and shear* properties significantly influence CO, with marginal probabilities of 0.736 and 0.696, respectively. However, *density* does not apparently impact preference, with both low and high values exerting roughly equal influence (marginal probabilities of 0.521 and 0.480, respectively).

4.4.2 Regression Analysis Between MaxDiff Scores

The well-ordered visual rankings derived from the profile-level MaxDiff analysis suggested potential correlations among the visual perceptions of FL, SU, and CO. To further explore the potential correlation and to understand more specific patterns of relevance between these visual perceptions across all eight virtual fabric items, an advanced analysis was undertaken, involving the use of the best-worst scores (-1, 0, and 1) for the three visual perceptions. These scores were input in ordinal logistic regression modelling. Specifically, the CO score was assigned as the ordinal dependent variable, with the FL and SU scores serving as predictor variables. This is because FL and SU have been identified as the two principal descriptors of visually perceived clothing movement, as deduced from the previous phase. These descriptors are tangible and illustrative of the concept of CO.

Before examining the model fit, a contingency analysis was conducted to assess potential relationships between any two categorical variables: CO and FL, CO and SU, and FL and SU. The outcomes of this pre-analysis are presented in the mosaic plots of the contingency analysis in Figure 16, which display the proportion of each score count relative to the total number of observations. Additionally, Table 21 further details the statistical parameters.

Figure 16

Summary of MaxDiff Score Contingency Analysis: CO vs. FL, CO vs. SU, SU vs. FL

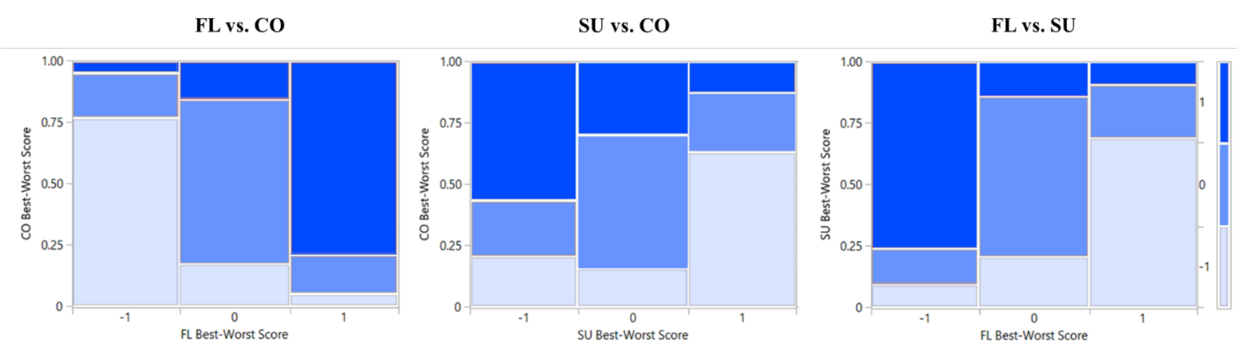


Table 21

Comparison of Contingency Analysis Results

Variable Comparison	FL vs. CO	SU vs. CO	FL vs. SU
Sample Size (N)	2880	2880	2880
Degrees of Freedom (DF)	4	4	4
-LogLike	1097.739	414.386	861.904
R-Square	0.347	0.131	0.272
ChiSquare (Likelihood Ratio)	2195.478	828.771	1723.807
ChiSquare (Pearson)	2262.444	860.250	1821.110
Prob > ChiSq	<.0001*	<.0001*	<.0001*

Note. In the table, the sample size (N) is consistently 2880, confirming that the total number of observations remains uniform across the three visual perception studies. The Degrees of Freedom (DF) are also consistent at 4, indicating the number of categories in the score variable is constant at 3 (-1, 0, 1) for all tables.

Table 21 shows that the consistency in sample size and degrees of freedom provides a reliable foundation for comparing the models. Table 21 also indicates variations in the -LogLike values among the models, with the FL vs. CO model showing the highest (-LogLike 1097.739) and the SU vs. CO model having the lowest (-LogLike 414.386). This suggests that the SU vs. CO model has the best fit among the three, while the FL vs. CO model has the least fit. The R-square values suggest that the FL vs. CO model has the strongest association between two categorical variables, while the SU vs. CO model has the weakest. This indicates that, within the context of the model, the visual perception of flexibility is a better predictor of variation in comfortability, while the perception of supportability is less effective in explaining comfortability. Additionally, both the Likelihood Ratio and Pearson tests yield varying chi-square values for each aspect, but all demonstrate p-values less than 0.0001. The results revealed statistically significant associations in all models, underscoring the relevance of these visual-tactile perceptions as the foundational basis for conducting the ordinal regression modeling.

The ordinal logistic regression modelling results are presented in Table 22. As the table shows, the FL score and SU score (the predictor variables) demonstrate statistical significance in relation to the CO score (the ordinal dependent variable). This significance is evidenced by the Logworth values of 324.911 and 12.782, respectively, and the extremely low p-values of 0.000.

Table 22

Ordinal Logistic Regression Results Between MaxDiff Scores

Parameters	Value / P-value
FL Score Logworth	324.911 / 0.000
SU Score Logworth	12.782 / 0.000
Model Chi-Square	2149.814
Degrees of Freedom (DF)	4
Model P-Value	<.0001*
R-Square	0.340
Lack of Fit Chi-Square	156.829
Lack of Fit P-value	<.0001*
Intercept[-1] Estimate	1.5853
Intercept[0] Estimate	4.2945
SU Score[0 to -1] Estimate	-0.8775
SU Score[1 to 0] Estimate	-0.5084
FL Score[0 to -1] Estimate	-2.2436
FL Score[1 to 0] Estimate	-3.1519

The model chi-square value (2149.814) and model p-value (<.0001*) indicate that the model incorporating FL and SU scores as predictors is significantly more effective than a model without these predictors. This result validates the relevance of these scores in explaining the variability of the CO score.

Given the ordinal nature of the model and the coding of predictors (as -1, 0, and 1), the general equation format is:

$$log\left(\frac{P(Y\leq j)}{P(Y\geq j)}\right) = \beta_0{}^{(j)} + \sum(\beta_i \times X_i) \tag{1}$$

Where β_0 is the intercept for category j (each intercept is used to calculate the log odds of being in a lower category versus the higher categories), β_i are the coefficients for the predictor variables, and X_i are the predictor variables (UCLA: Statistical Consulting Group, 2011).

Using the parameter estimates in Table 22, the equations for the two categories are:

For the first category representing the log odds of CO score being -1 (the lowest) vs. 0 or 1 (the combined highest) when Fl and SU scores are at their reference levels:

$$log\ \left(\frac{P(CO\leq-1)}{P(CO\geq-1)}\right) = 1.5853 - 0.8775 \times SU_{0--1} - 0.5084 \times SU_{1-0} - 2.2436 \times\ FL_{0--1} - 3.1519 \times FL_{1-0} \quad (2)$$

For the second category representing the log odds of CO score being -1 or 0 (the combined lowest) vs. 1 (the highest) when FL and SU scores are at their reference levels:

$$log\ \left(\frac{P(CO\leq0)}{P(CO\geq0)}\right) = 4.2945 - 0.8775 \times SU_{0--1} - 0.5084 \times SU_{1-0} - 2.2436 \times\ FL_{0--1} - 3.1519 \times FL_{1-0} \quad (3)$$

In equations (2) and (3), SU_{0--1}, SU_{1-0}, FL_{0--1}, and FL_{1-0} represent the SU and FL scores for the respective comparisons.

The R-square value in Table 22 further suggests that about 33.98% of the variability in the CO score can be attributed to the model incorporating FL and SU scores. However, the Lack of Fit test, with its chi-square value of 156.8294 and a p-value of less than 0.0001, implies that the model may not perfectly fit the data. This indicates that while the model is statistically significant, there may be other factors or nuances in the data that it does not fully account for.

In summary, the ordinal logistic regression model with FL and SU scores as significant predictors explain a considerable portion of the variability in the CO score. However, the noted lack of fit suggests that there may be additional complexities in the data that the model does not capture entirely, indicating room for further refinement or exploration of other influencing factors.

4.4.3 Regression Analysis Between Utility Scores and Virtual Fabric Parameters

The visual rankings derived from the profile-level MaxDiff analysis also indicated potential correlations between the FL, SU, and CO visual perceptions and the three virtual fabric parameters. Furthermore, the conjoint three virtual fabric parameters, *stretch and shear*, *bending*, and *density*, suggested that these parameters might interactively influence visual perceptions. To delve into this, the regression relationships between virtual fabric parameters and the FL, SU, and CO marginal utility scores were analyzed individually. For a comprehensive investigation of the potential regression relationship between the scores and the interaction among virtual fabric parameters, a full factorial approach incorporating the parameters *Stretch and Shear*, *Bending*, and *Density* was employed as model effects. This analysis revealed that all three models exhibited strong fit, as evidenced by high R-square values (FL: 0.9428, SU: 0.7991, CO: 0.8926), indicating that the models accounted for approximately 80% to 95% of the variance in responses. The results of the parameter estimates were detailed in Tables 23a, 23b, and 23c.

Table 23a

Parameter Estimates of the Linear Model (Responses: FL Utility Scores)

Independent Variables and Intercept	Estimate	Std Error	T Ratio	P-Value
Intercept	3.906e-12	0.00468	0.00	1.0000
Attr 2(B)[10]	0.844	0.00468	180.31	<.0001*
Attr 1(SS)[10]	0.363	0.00468	77.51	<.0001*
Attr 2(B)[10]*Attr 3(D)[10]	-0.341	0.00468	-72.88	<.0001*
Attr 1(SS)[10]*Attr 2(B)[10]*Attr 3(D)[10]	-0.134	0.00468	-28.54	<.0001*
Attr 1(SS)[10]*Attr 2(B)[10]	0.112	0.00468	23.94	<.0001*
Attr 1(SS)[10]*Attr 3(D)[10]	-0.112	0.00468	-23.92	<.0001*
Attr 3(D)[10]	-0.067	0.00468	-14.31	<.0001*

Table 23b

Parameter Estimates of the Linear Model (Responses: SU Utility Scores)

Independent Variables and Intercept	Estimate	Std Error	T Ratio	P-Value
Intercept	1.562e-11	0.009906	0.00	1.0000
Attr 2(B)[10]	-0.992	0.009906	-100.2	<.0001*
Attr 2(B)[10]*Attr 3(D)[10]	0.308	0.009906	31.13	<.0001*
Attr 1(SS)[10]*Attr 2(B)[10]*Attr 3(D)[10]	0.178	0.009906	18.00	<.0001*
Attr 1(SS)[10]*Attr 2(B)[10]	0.158	0.009906	15.96	<.0001*
Attr 1(SS)[10]*Attr 3(D)[10]	0.141	0.009906	14.20	<.0001*
Attr 1(SS)[10]	-0.119	0.009906	-12.02	<.0001*
Attr 3(D)[10]	0.011	0.009906	1.12	0.2627

Table 23c

Parameter Estimates of the Linear Model (Responses: CO Utility Scores)

Independent Variables and Intercept	Estimate	Std Error	T Ratio	P-Value
Intercept	-1.04e-11	0.005771	-0.00	1.0000
Attr 2(B)[10]	0.574	0.005771	99.48	<.0001*
Attr 1(SS)[10]	0.471	0.005771	81.65	<.0001*
Attr 1(SS)[10]*Attr 2(B)[10]	0.307	0.005771	53.14	<.0001*
Attr 2(B)[10]*Attr 3(D)[10]	-0.283	0.005771	-49.04	<.0001*
Attr 1(SS)[10]*Attr 2(B)[10]*Attr 3(D)[10]	-0.085	0.005771	-14.70	<.0001*
Attr 1(SS)[10]*Attr 3(D)[10]	-0.074	0.005771	-12.88	<.0001*
Attr 3(D)[10]	-0.060	0.005771	-10.40	<.0001*

Note. The three tables presented the estimated parameters for the linear model, using a full factorial approach with the three virtual fabric parameters as independent variables and the marginal utility score for each perception as the dependent variables. *Attr 1(SS)* represented *Stretch and Shear*, *Attr 2(B)* signified *Bending*, and *Attr 3(D)* denoted *Density*. Specifically, all models used virtual fabric parameters in the low value case (10) as variables. The estimates for all independent variables are coefficients that signify the degree of correlation. All independent variables were organized based on their degree of correlation (the absolute value of the coefficient) to each model.

In the regression model to predict the FL score, all independent variables emerged as significant predictors, each with a p-value less than 0.0001. Among these variables, the single factor, low-value *Bending* exhibited the most substantial influence on FL, presenting a positive estimate of 0.844. This indicates that an increase of one unit in low-value *Bending* is associated with an increase of 0.844 units in the FL utility score. The *Stretch and Shear* factor was the second most influential, with a positive estimate of 0.363. The interaction between low-value *Bending* and low-value *Density* ranked third in terms of influence, carrying a negative estimate of -0.341. This suggests that a simultaneous unit increase in both low-value *Bending* and low-value *Density* would lead to a decrease of 0.341 units in the FL utility score. Among these factors, *Density* had the least impact, marked by a negative estimate of -0.067, yet its influence remained significant. The results underscored the predominant effect of *Bending* and *Stretch and Shear* on enhancing the visual perception of flexibility, with *Bending* being the most impactful. *Density*'s influence was minimal but notably significant.

In the regression model for the SU score, all independent variables except for the single factor of *Density* (p-value=0.2627) emerged as significant predictors. Low-value *Bending* is notably associated with a decrease of 0.992 units in the SU utility score, as highlighted in Table 23b. The second most impactful factor is the interaction between low-value *Bending* and low-value *Density*, with a positive estimate of 0.308. This finding aligns with earlier discussions in Section 4.4.1 on MaxDiff analysis results, where it was suggested that, among the fabric items displayed, when fabric deformation is evident, as indicated by lower *Bending* values, a lower *Density* might more aptly signify supportability.

For the CO score's regression model, all independent variables were significant predictors, each with a p-value less than 0.0001. Low-value *Bending* again showed the most significant impact on CO, with a positive estimate of 0.574. The *Stretch and Shear* factor followed as the second most influential, with a positive estimate of 0.471. The interaction between low-value *Bending* and low-value *Stretch and Shear* was the third most impactful, having a negative estimate of -0.307. Density had the least effect, marked by a negative estimate of -0.060, yet its significance remained. Comparing the models for FL and CO scores revealed similarities in the two most influential factors, *Bending* and *Stretch and Shear*, with increases in either factor enhancing the visual perception of comfortability. The notable difference lies in the ratios of influence and the third most influential factor: low-value *Bending* and low-value *Density* interaction for flexibility, versus low-value *Bending* and low-value *Stretch and Shear* interaction for comfort.

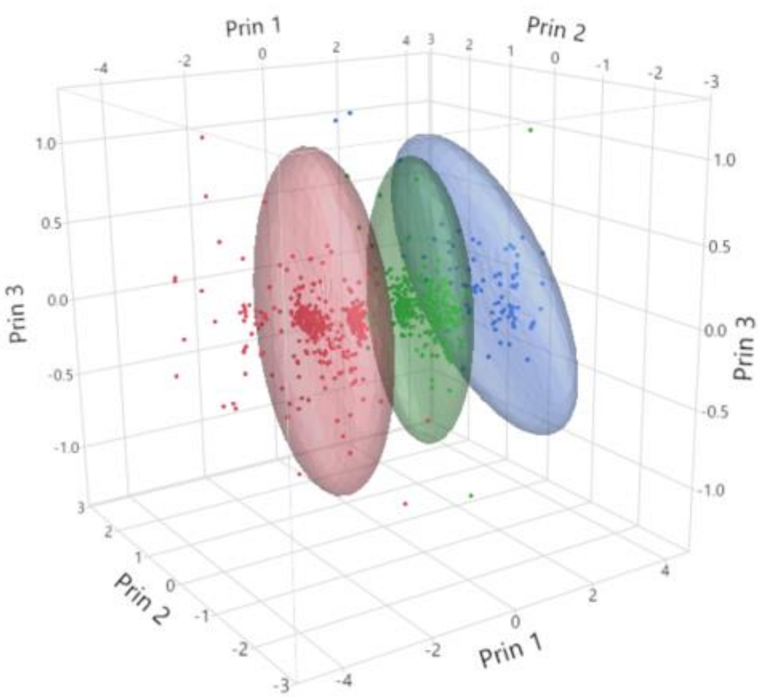
The analysis across all three models illustrated that the single factor of *Bending* had strongest influence on all three visual perceptions. *Stretch and Shear* took second place in affecting flexibility and comfortability. This consistency resonates with the visual rankings discussed in Section 4.4.1. *Density*, though the least influential overall, became significant when interacting with low-value *Bending* for supportability perception. Furthermore, all three models underscored the critical role of considering interactions among the three virtual fabric parameters, as these interactions significantly affected each utility score.

4.4.4 Virtual Fabric Cluster Analysis

Delving further into the analysis, the marginal utility scores were employed for clustering the eight virtual fabric variants involved in the present study. The K-means clustering analysis was utilized to evaluate various cluster numbers, with the conclusion that three clusters (NCluster=3) most effectively categorized the eight virtual fabric video items across all 30 survey questions, as this categorization facilitated a coherent interpretation of the clusters' relevance to the three targeted perceptions. In the preprocessing step of the clustering analysis, Principal Component Analysis (PCA) reduces data dimensionality by projecting it onto a lower-dimensional subspace, to eliminate noise and redundant features (Ding and He, 2004, Zhu et al., 2019, as cited in Fourar et al., 2021). Through K-means clustering, a total of 2880 data samples (3 video items per question × 10 questions per targeted perception × 96 participants) representing all responses to each targeted perception were organized as shown in Figure 17, the 3D biplot to visualize the distances between each cluster's data. Additionally, this data was graphically represented in Figure 18 for observing the distribution of the three clusters across all question choices, namely the virtual fabric video items. This approach enabled the identification of specific virtual fabric items to which these responses were targeted, thereby determining the *representative virtual fabric* *items* as outlined in Table 24. Table 24 also detailed the characteristics of these three clusters, including their marginal utility scores in FL, SU, and CO. Based on the degree of visually perceived comfortability, the clusters were named *Suboptimal Comfort*, *Standard Comfort*, and *Supreme Comfort*. This naming strategy was based on the distinct levels of comfort each cluster embodies, because among the three visual-tactile perceptions analyzed, it is also comfortability that holds the paramount interest.

Figure 17

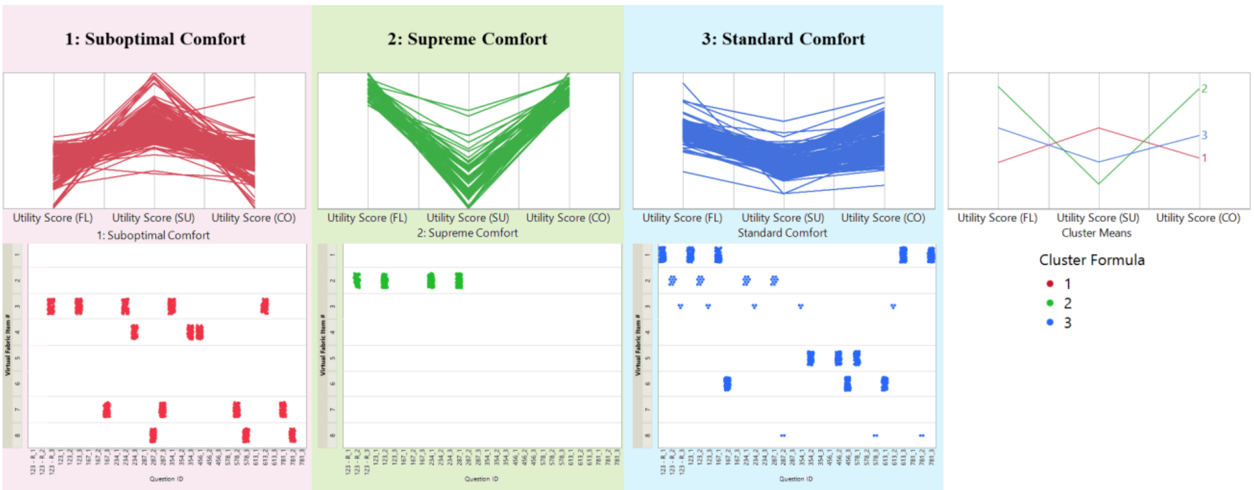
3D Biplot of Three Clusters



Note. This figure visually represented the results of the K-means clustering analysis on survey data regarding perceptions of virtual fabric video items. The plot illustrated how responses are distributed within each cluster and the spatial relationships between clusters. Three distinct clusters, each represented by different colors—red for *Suboptimal Comfort*, green for *Supreme Comfort*, and blue for *Standard Comfort*—corresponded to the clusters identified in Figure 16 and Table 24. It is important to recognize that the axes labeled *prin 1*, *prin 2*, and *prin 3* represented combinations derived from the original variables (FL, SU, and CO marginal utility scores), indicating that there isn't a direct one-to-one match between these principal components and the original variables. The 3D biplot employed these three principal components for visualization, as they encapsulated the most significant patterns and relationships within the dataset.

Figure 18

Comparative Visualization of Three Clusters (Parallel Coordinate and Scatterplot by Question ID)



Note. The top row are parallel coordinate plots for the three comfort clusters, showing the FL, SU, and CO marginal utility scores differed across individual data samples within each cluster. The rightmost one displayed the plots of the means, to visualize the differences in the marginal utility scores among the clusters representatively. The bottom row presented scatterplots for each cluster, showing the distribution and concentration of data points for each question and each virtual fabric item within the clusters. These plots were the basis for classifying the virtual fabric items according to the results of the cluster analysis.

Table 24

Marginal Utility Scores of Three Clusters

Cluster	Virtual Fabric Items	Utility Score (FL)	Utility Score (SU)	Utility Score (CO)
1: Suboptimal Comfort	V3, V4, V7, V8	-0.779	0.928	-0.524
2: Supreme Comfort	V2	2.053	-1.725	1.963
3: Standard Comfort	V1, V5, V6	0.512	-0.682	0.285
F value		8919.799	3666.906	3964.673
P-value		<0.0001*	<0.0001*	<0.0001*

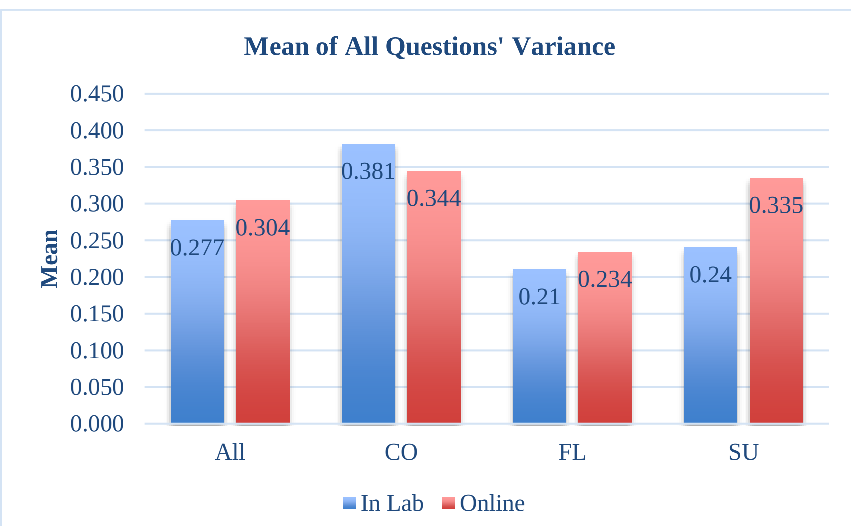
Figure 18 offered a comprehensive visualization of the perceptual pattern and representative virtual fabric variants for each cluster. The first cluster, *Suboptimal Comfort*, included virtual fabrics with the lowest comfortability perception among the three clusters. This was predominantly influenced by low-value flexibility perception and high-value supportability perception. The virtual fabric variants in this cluster, namely V3, V4, V7, and V8, were characterized by high-value bending properties. In contrast, the second cluster, *Supreme Comfort* was marked by an exceptionally high visual perception of comfortability, driven by very high flexibility and very low supportability levels. This cluster included only V2, distinguished by low stretch and shear properties, low bending values, and high density. As mentioned in the previous MaxDiff analysis, these attributes contribute to a highly deformable appearance in virtual fabric motion simulations. Lastly, the third cluster, *Standard Comfort*, encapsulated fabrics with a neutral, generally acceptable level of visual comfortability perception. This cluster represented a balance between the extremes of the other two clusters, reflecting a more moderate perception of fabric attributes in terms of flexibility, supportability, and comfortability. V1, V5, and V6 were in this cluster. Furthermore, as evidenced in Table 24, the F value for each utility score is very high, and the p-value (<0.0001*) for each utility score indicated that there were significant differences in utility scores across the three clusters. This underscored that the clustering was meaningful regarding the utility scores for FL, SU, and CO.

4.4.5 Observer Variability Assessment

The assessment of interobserver variability in the responses of online survey participants involved calculating the variance across different observers' responses. These metrics were then compared to those derived from the in-lab group responses, which served as a control group. A comprehensive comparison for all 30 questions of the survey involving an extensive analysis of standard deviations and variances for a total of 90 choices, was included in Appendix G. The extensive data is presented in line plots for better visualization. Figure 19 presented a bar chart comparing the online (with 96 observers) and in-lab (with 18 observers) results in a more representative manner. The comparison is structured both by question types in the survey—focusing on flexibility, supportability, or comfortability—and in terms of the survey as a whole.

Figure 19

Comparison of Interobserver Variability Between Online and In-Lab Groups



Note. In the figure, along the X-axis, the label "ALL" refers to all questions, "CO" designates the questions about comfortability, "FL" pertains to questions about flexibility, and "SU" indicates those concerning supportability. The chart represented the mean value of variance observed across all survey questions.

A notable finding from this comparison is the difference in variance mean values, with the total online responses exhibiting a variance mean of 0.304, greater than the in-lab group's 0.277. This suggests that the responses from the online survey were less consistent across different observers compared to the in-lab responses. This observation implies that standardizing the visual environment and conditions for viewing the simulation videos could enhance the stability of interobserver variability.

In the consistency analysis aimed at assessing intraobserver variability, the consistency of the MaxDiff scores from duplicated question blocks (comparing the three visual perceptions in V1, V2, V3) was computed across two sessions for the same observer in both in-lab and online settings. The percentages of participants who responded identically to the duplicated question blocks are presented in Table 25. An interesting observation was that the percentage was higher in the online setting than in the in-lab setting, which served as the control group. A possible explanation for this increased consistency in the online setting could be attributed to the larger sample size compared to the in-lab group. Additionally, participants completing the survey online likely did so in familiar environments (such as their homes), which reduced external distractions and promoted more consistent responses.

Table 25

Comparison of Intraobserver Variability Between Online and In-Lab Groups

Group	All Questions	FL Questions	SU Questions	CO Questions
Online	75.7%	79.2%	76.0%	71.9%
In-Lab	61.1%	61.1%	61.1%	61.1%

5. FURTHER DISCUSSIONS AND CONCLUSIONS

This concluding chapter revisits the essential findings of the study, emphasizing their significant impact on the expansive field of virtual fabric and its influence on the visual perception of clothing movement. Initially aimed at interpreting the nuances of viewers' visual perceptual changes in response to variations in simulations, the research has revealed crucial insights that can aid 3D apparel designers in more accurately depicting clothing movement features through 3D motion simulations.

The chapter systematically provides a summary and further discussion of the findings, highlighting their relevance and utility, and offering valuable insights for professionals of 3D apparel design. Furthermore, the chapter acknowledges and discusses the limitations encountered during the research, providing a transparent overview of the study's scope and boundaries. Additionally, the chapter also presents forward-looking recommendations for future research, which recognizes the dynamic and continually evolving nature of fabric representation using 3D simulation technology.

5.1 The Impact of Virtual Fabric Parameters on Visual Perception of Clothing Movement

During the focus group discussions in Phase 1, the responses to perceiving the six virtual fabric variants were generally consistent across both groups. The orderly flow of the discussion, particularly the order in which fabric video observations were presented, might have contributed to the consistency in participant responses. This trend could also be explained by the possibility that participants' perceptions of clothing movement in the 3D clothing simulations—despite its virtual nature—might have been shaped more by the objective visual data presented than by personal biases or subjective interpretations.

The comprehensive analysis in Phase 2 conclusively demonstrated that, within the context of the provided loose jumpsuit simulation, *bending* properties were the most influential virtual fabric parameters affecting visual perception of *flexibility*, *supportability*, and *comfortability*. This finding is in harmony with the previous empirical research of Yang et al. (2014) and Jimba et al. (2021), which found that visual softness in the context of real fabrics is significantly influenced or even predictable by fabric bending properties. Building on these prior studies, the current research further established that *bending* properties are the most visible attributes of simulated fabric in motion, particularly in simulated activewear. Both very high and very low values of *bending* properties were distinctly recognized in the assessment of clothing movement visual perception and visual comfort.

Stretch and shear properties emerged as the second impactful factors, consistently influencing visual perception of *flexibility*, *supportability*, and *comfortability*, with positive effects on perception of *flexibility* and *comfortability*, along with a slight negative effect on *supportability*. The impact of *stretch and shear* properties on perception of *comfortability*, along with the effect arising from its interaction with bending properties, represents a more significant proportion than its single effect on perception of *flexibility*. The impact of *stretch and shear* properties has the potential to distinguish virtual fabrics as either *standard comfort* or *supreme comfort* within the cluster analysis. The minor role of *stretch and shear* properties also suggests that visual perception could be less sensitive to fabric stretching under tension than tactile sensation, especially when the fabric is presented in a human-scale context.

Density, meanwhile, had the least impact on visual perception in the context of 3D apparel simulation in motion. Preliminary subjective simulation tests indicated that density values apparently influence the appearance of a virtual fabric's static drape. However, its impact is less pronounced compared to *bending* and *stretch and shear* properties, especially concerning visual perception of *supportability*. A substantial impact on the visual perception of *supportability* is discernible through the interactions of *density* and *bending*. This could be because lower density implies reduced gravity-induced draping and greater conformity to body movements, thereby enhancing perceived *supportability*. Additionally, the minimal role of *density* resulting from Phase 2 analysis could be attributed to the visual sense being less sensitive to weight compared to touch. This implies that visually, larger deformations may be necessary to perceive weight and tension, or additional visual cues like visibly thick fabric texture, may be needed to enhance the perception of mechanical properties.

5.2 The Interplay of Flexibility, Supportability, and Comfort

In phase 1 of this study, the visual perception descriptors *flexible/not flexible* (FL) and *supportive/not supportive* (SU) were identified through focus group discussions in the context of 3D fabric motion simulation. Based on participant responses, FL is defined as the fabric's capacity to move with the body, while SU relates to the fabric's tendency to gap and wrinkle, with more gapping and wrinkling indicating less support. This phase involved two types of simulated videos: one showing fabric being pulled and another featuring an avatar dancing in a jumpsuit, with a focus on the abdomen, crotch, and leg opening areas. Phase 2 progressed to use the simulated jumpsuit video in a MaxDiff Conjoint Approach survey, collecting responses on the perceived flexibility, supportability, and comfortability of the virtual fabrics. The descriptors FL and SU were included in each survey question to guide observers' visual assessments.

Ordinal logistic regression analysis in Phase 2 revealed that both clothing-movement-related descriptors influenced visual comfort perception, albeit in different ways, through the medium of 3D jumpsuit simulation motion video. The MaxDiff preference for evaluating FL aligns more closely with *comfortable/not comfortable* (CO), suggesting that these perceptions arose from similar factors, notably the *stretch and shear* parameters and the *bending* parameters of the simulated fabric videos. This finding implies that the description of FL, focusing on the jumpsuit's tendency to bounce and move with the body in motion, is more closely related to the nature of visual comfort compared to SU. FL also better predicted variance in visual perception of CO, particularly in distinguishing between extremes of comfort and discomfort. FL also significantly influenced SU, as indicated by contingency analysis results. From this analysis, FL emerged as a major factor in adjusting the overall perception of CO. Essentially, *not flexible* tended to equate to *not comfortable*, while *flexible* generally indicated *comfortable*. Conversely, SU acts as a more subtle factor, fine-tuning comfort within a less sensitive range. Optimal comfortability tended to be achieved within a specific range of supportability; falling outside this range tended to result in discomfort. The findings from the regression analysis examining the relationships between the virtual fabric parameters and the three MaxDiff scores, further supported this line of reasoning. This analysis revealed consistent patterns in the effects of the variables on the CO and FL scores across the models. Specifically, the individual factors—*stretch and shear,* and *bending* parameters—and their interactions generally had a negative effect on the CO and FL scores, indicating that lower values of these parameters enhanced perceptions of flexibility and comfort in the study. In contrast, the *density* parameter positively affected these perceptions, suggesting that lower density values diminish the visual sense of flexibility and comfort. These patterns did not extend to the SU score. For the SU score, the primary influencer was the *bending* properties alone, with a complex relationship existing between *bending* properties and *density*: a low value in *bending* parameters tended to reduce the perception of supportability, but when combined with low *density*, these factors together appeared to improve it.

5.3 Virtual Fabric Comfort Clusters

Through a cluster analysis based on marginal utility scores reflecting preferences for *flexibility*, *supportability*, and *comfortability* perception, the eight virtual fabric variants, derived from varying parameters, have been categorized into three distinct clusters: *suboptimal comfort*, *standard comfort*, and *supreme comfort*. This classification is particularly intriguing as it originated from the perspective of visual perception in women's activewear, within the context of 3D activewear simulation, which is a domain that has not been previously explored.

In analyzing the three resultant clusters, it becomes apparent that the virtual fabric's visually perceived *supportability* plays an inhibitory influence on enhancing preferences for perceived *flexibility* and *comfortability*. The degree of this influence varies among the clusters. For instance, fabrics in the *supreme comfort* cluster exhibit a strong contrast between visual *comfortability* and *supportability*, as well as between *flexibility* and *supportability*. In contrast, the *suboptimal comfort* and *standard comfort* clusters represent fabrics with more moderate contrasts in these aspects.

Focusing on the most influential virtual fabric parameter, namely *bending* values, it is observed that high-value *bending* properties typically result in fabrics classified under *suboptimal comfort*. Conversely, fabrics achieving *supreme comfort* are characterized by low-value *bending* properties, coupled with low *stretch and shear* properties and high *density*. The remaining fabric variants, which balance the deformation effects of *stretch and shear* properties with *density*, fall into the *standard comfort* category. This approach uses *bending* values as a starting point to categorize virtual fabric parameters along a visual comfort perception spectrum, presenting a promising avenue for future investigations. It offers an insightful method to understand and predict the comfort perception of virtual fabrics based on their parametric properties in a simulated environment.

5.4 Research Implications

This study distinctly elucidated the logic underpinning the construction of virtual fabric's mechanical properties, a logic markedly different from that of real fabrics. The subjective simulation test in Phase 0B has revealed a notable distinction: in the CLO software, there exists no interdependent relationship between *stretch and shear*, *bending*, and *density* properties, unlike in actual fabrics. This distinct characteristic allows for the independent manipulation of virtual fabric's mechanical properties, facilitating a closer approximation of virtual fabrics to their real-world visual presentations. It has also been found that within these parameters, the approximate values in common units are scaled to a range corresponding to a coefficient value in CLO. This is equivalent to dividing the value measured in common units into a total of 100 levels of intensity, thus the CLO software can process the actual measures more easily. By understanding this relationship, future researchers can make informed decisions about the values to input into the CLO software and generate the desired fabric behavior. This observation also points to a potential information gap between actual fabrics and their digital replicas in the CLO software. This gap may arise from the simplification processes implemented for computational efficiency in the fabric properties' digitization, highlighting a trade-off between the convenience of digital modeling and the nuanced complexity of real-world fabric properties.

The genesis of this study lies here to provide empirical insights for 3D apparel designers and a broader range of users of 3D apparel CAD systems, especially those from a real fabric design and manufacturing background. It seeks to enhance understanding of the utility of virtual fabric parameters for more accurate simulations of fabric mechanical performance. Through this research, the study successfully demonstrates how adjustments in CLO virtual fabric's *stretch and shear*, *bending*, and *density* properties impact the visual expression of clothing movement, particularly in a simulated loose activewear context. This approach offers a more tangible and apparel-industry-specific example than merely draping a piece of fabric.

A significant advancement of this study is the introduction of *flexible* and *supportive* as descriptors of clothing movement, along with their corresponding visual cues in simulation. This development bridges the gap between visual-tactile perception and the simulated fabric motion scene, moving beyond traditional touch-based descriptors like “soft” or “tough,” and potentially reducing ambiguities arising from sensory synthesis. Moreover, this study pioneered the use of dynamic simulated apparel visual stimuli in evaluating visual perception. It provides comprehensive guidance on simulating fabric and apparel animations in 3D CAD systems (specifically CLO) for research purposes and offers empirical evidence to support future research in this field. This represents a significant breakthrough, paving the way for more nuanced and accurate simulations that resonate with both the visual and tactile aspects of fabric perception.

5.5 Research Limitations and Areas for Future Research

While this study marks significant advancements, it also acknowledges some limitations. The results of this study were obtained using virtual fabric presentations that better highlight visual elements (e.g., the fabric color contrasts sharply with the background, and the fabric appears high-quality). Therefore, this conclusion may not be generalizable to other fabric appearances. For example, if the color of the fabric is not well-highlighted, the perception of its visual details, such as wrinkles, will be affected. Further research should explore this point to investigate how variations in fabric appearance can influence the visual perceptions of clothing movement.

To ensure higher completion rates and reduce participant burden, the survey design intentionally limited repeated observations. However, despite these efforts, nearly 40 instances of uncompleted survey were recorded, indicating that even a simplified design may not fully address participant drop-off issues. Future research could potentially involve more extensive data collection efforts, such as recruiting a larger and more diverse participant sample or conducting longer-term surveys to allow for repeated observations.

The survey design also presents limitations in the statistical assessment of observer variability. The present study used descriptive analysis to report results, which does not yield reliable conclusions through inferential statistical tests. Considering the lack of existing experimental studies in similar surveys to enhance the reliability of observer variability assessment for the present study, future research could focus on incorporating additional conditions into the survey design to obtain more data points, enabling a more systematic statistical analysis. For instance, to improve the interobserver variability assessment, a larger number of in-lab participants could be recruited to match the number of subjects in the online survey. This would allow the in-lab group to serve as a more effective benchmark for the interobserver variability assessment. To enhance intraobserver variability assessment, more duplicated questions should be included to calculate the standard deviation or Standard Error of Measurement (SEM) of these differences, so as to facilitate the use of the Intraclass Correlation Coefficient (ICC) for comparison (Popovic & Thomas, 2017).

The exclusive focus on virtual fabrics within the CLO software means that the principles behind the virtual fabric parameters tested in the present study may not be applicable to other CAD software. In addition, the present study without incorporating real fabric comparisons, also serves as a limitation of this study. This approach limits the ability to directly compare the physical properties and tactile sensations of real fabrics with their virtual counterparts. Future studies could benefit from incorporating analysis of real fabrics alongside virtual simulations, to allow researchers, particularly those with expertise in real textiles only, to conduct side-by-side comparisons, evaluating the fidelity of virtual simulations in replicating the look, feel, and behavior of actual textiles.

Another limitation is the lack of an objective exploration of visual elements in the simulation test in Phase 0B. Future studies could extract and analyze specific visual elements from the videos, such as motion descriptors, to establish a more objective correlation with the visual perception of clothing movement. This approach could provide a more grounded understanding of the clothing movement descriptors, *flexible* and *supportive*. Additionally, Phase 1 results hinted at drapability being a potential indicator of activewear functionality for different levels of sports impact (low, medium, or high). Future research in this area could involve conducting a similar MaxDiff Conjoint evaluation survey to investigate the relationship between virtual fabric parameters of drapability and their visual perception under motion simulation in various sports contexts.

Finally, Phase 2's MaxDiff Conjoint survey exclusively utilized a loose jumpsuit simulation as visual stimuli. To broaden the understanding and provide comparative insights, future research could also incorporate fabric pulling videos. This would allow for a comparative analysis of responses between viewing fabric pulling videos and viewing simulated activewear, offering a richer perspective on how different types of visual stimuli affect the perception of virtual fabrics.

APPENDICES

Appendix A: Analysis of descriptions concerning the look and feel of fabrics F1 to F6

F1:

Subcategories	Sub-subcategories	Themes	Codes	Subcodes	Representative Quotes
Description of how F1 looks and feels	Fabric appearance and performance	Flexibility	**good stretchability (3)**	NMI	"I would say that it's got a good elasticity..."
				MI	Being pulled a little bit: "(in the loose activewear video) Like at the bottom, it seems to be like pulling a bit, but that could indicate maybe like a stretch, going like vertically"
			Stretchable (2)	MI	Bounce back strongly (Bounce but not up and down, go down lower after turn back): "When we were looking at the first clip the fabric to me looked heavy like it it's like heavy and elastic because like when you pull back it like bounces but it like doesn't like bounce up and down. It kind of goes down lower. So for me this looks heavy..."
				NMI	"I feel like it's like on the beach chairs that give it a sort of elasticity"
			All-way stretch	MI	Lay on the body pretty well: "...it's able to stretch in a lot of different ways. And like it lays on the body pretty well"
			Good shape retention	MI	Bounce/Snap back easily: "When I was watching the videos of it being pulled apart, I think it seemed like ... good retention ... Because it seems like it snaps back pretty easy, which is something that you would want in like athletic wear."
			flexible(4)	MI	Soft creases/wrinkles move with the body: "The creases to move with her body. It's not super stiff, you can see a lot of movement, even in the tighter fitting one. Like, as she moves like back and forth, you see wrinkles and it's

Subcategories	Sub-subcategories	Themes	Codes	Subcodes	Representative Quotes
					just like it moves with the body really well."
				NMI	"I would just gonna say it's really flexible. It's like, looks like a really flexible fabric..." "Looks like she's able to like move quite easily."
		Drapability	good flow (2)	NMI	"..it's got like a good flow."
			Good drape	NMI	"And then in the video of the looser jumpsuit, I think it had like a pretty decent drape to it..."
		supportability	Tight (2)	MI	Being pulled a little bit: ""I think for me, it's the crotch area to the top seems too tight, which is why it's creating the creases but that might just be me being picky with it.""
			Not compressive	NMI	" I will feel it will be comfortable to wear in your body. It will not be very tight and it will not give you pressure."
			Soft (4)	NMI	"Yeah, on the tight one. You can. I feel like it looks softer. Like kind of, like the Lululemon fabric that's really soft." "I think this fabric looks much more softer because maybe I can see little of the texture on the fabric...like knit jersey texture"
		weight	Heavy weight (2)	MI	Bounce back strongly (Bounce but not up and down, go down lower after turn back): "When we were looking at the first clip the fabric to me looked heavy like it it's like heavy and elastic because like when you pull back it like bounces but it like doesn't like bounce up and down. It kind of goes down lower. So for me this looks heavy..."
				NMI	" ... it just looks like a heavier fabric (in the fabric videos)."

Subcategories	Sub-subcategories	Themes	Codes	Subcodes	Representative Quotes
			Medium weight (2)	MI	held down by gravity: "...it actually seemed like maybe it was like a midweight fabric because of the way it kind of like is held down by gravity."
					Not pleating, thick folds move with the body: "And the way that the almost it’s not pleating, but the way the like the folds are kind of moving around. They’re there I’m trying to find the best word for this. The folds are thicker..."
				NMI	"...but then the second one and the third one on the fabrics (the twisting and sliding videos), they start to look lighter just based on the twisting."
			Light weight (2)	NMI	"But then on the model, it looked much more light and it looked more like like active wear on the models..."
		surface features	Porous	NMI	"...it just looks like a heavier fabric. But like more porous kind of ..."
			Grainy	NMI	"I think it might just be my computer’s just making it look more grainy than it is"
			Rough	NMI	"But if I look at the fabric stretch test, I see the surface roughness clearly..."
			brush/not shiny (2)	NMI	"(Mod: What visual cues gave you the soft feeling?) I’d say because it’s not very shiny when it’s tight on the body. Because a lot of active wear. It’s like, it has like a luster to it kind of whenever it’s stretched out. It’s like really compressive this looks like soft. I don’t know. Like brushed."
		comfortability	Not comfortable	NMI	"I think if I’m looking solely on the fabric, it doesn’t look comfortable."
			Comfortable	NMI	"I will feel it will be comfortable to wear in your body."
		possible fabric type	Beach chair fabric (2)	NMI	"I feel like it’s like on the beach chairs that give it a sort of elasticity. But like you can let water like go through I

Subcategories	Sub-subcategories	Themes	Codes	Subcodes	Representative Quotes
					feel like you've been swimming."
			Activewear fabric/good for activewear (3)	MI	Bounce/Snap back easily: "Because it seems like it snaps back pretty easy, which is something that you would want in like athletic wear."
				NMI	"But then on the model, it looked much more light and it looked more like like active wear on the models..."
			man-made/synthetic/blend fabric (3)	NMI	"I think it is a little manmade. It is not the like a cotton that is very soft and stretchy..."
			Rayon fabric (2)	NMI	"I guess a rayon." "I could definitely agree with the the rayon guess."
			Woven denim	NMI	" ...if I look at the fabric stretch test, I see the surface roughness clearly, it looks like woven denim texture … a little lighter woven, woven denim."

F2:

Subcategories	Sub-subcategories	Themes	Codes	Subcodes	Representative Quotes
Description of how F2 looks and feels	Fabric appearance and performance	Flexibility	good recovery	MI	Strongly bounce back: "But it looks like it had good recovery from the first video, like the bounce back seemed like very strong and easy to recover. "
			slow recovery (7)	MI	slowly undo itself: "And then after a while it'll like undo itself. So like here, like it slowly undoes itself, but like takes a while."
					stab, static, stick to the fabric itself: "So it kind of I feel like it's like stab like a static where it's like it's stuck to itself."

Subcategories	Sub-subcategories	Themes	Codes	Subcodes	Representative Quotes
					fabric hold its shape/position: "I also said like, it like holds its position or whatever the model does. And then it takes a while for it to do so like in the tight activewear when she like bends down, there's a wrinkle in the leg that holds its shape, and doesn't doesn't loosen itself up."
					stick on to model: "So like in the first activewear the loose one, like the fabric would like stick onto the model after they turned. "
				NMI	"And even like in the first video where you would stretch it, you would stretch it and then like, it takes some time to go back down."
			not moving with the body (5)	MI	**stick on to the model:** "So like in the first activewear the loose one, like the fabric would like stick onto the model after they turned."
			bad shape retention (3)	MI	little bounce, hold/maintain its shape: "Like it didn't really bounce back or anything. It kind of just held its own shape."
			Stretchable	NMI	"...But that can still stretch."
			Stretchy	NMI	"...because it was like stretchy. And you could tell that the way it stretched."
		Drapability	not flowy (3)	NMI	"... it could be and it's not made to be loose and flowy"
		supportability	**Stiff (6)**	NMI	"I don't know or like a like a double knit cotton something that's like, has pretty, like stiff qualities to it." "...it has like a lot of structure to it."
			loose/not tight (4)	MI	**gapping:** "... this one can like it's not very clear to see your body shape." "It kind of looks like in the back there, there might be like some, like gapping between her back and the

Subcategories	Sub-subcategories	Themes	Codes	Subcodes	Representative Quotes
					fabric."
			compressive/supportive (7)	MI	hold/maintain its shape: "but I think it has good compression in terms of maintaining the shape"
				NMI	"I feel like the second fabric is definitely made to be more of like a compression fabric because it's very, it feels very thick." "But it looks really compressive or it could be and it's not made to be loose and flowy." "I'm not saying it's not comfortable to wear but I feel like it'd be more of like, like for like a supportive garment or something that provides more compression when you're working out instead of something made to be light and flowy. "
			slightly soft	NMI	"It looks a little bit soft, but I can't really tell."
			not wrinkly (3)	MI	**no draglines:** "It doesn't really. Like there's no draglines or like, you know."
		Thickness	thick (4)	NMI	"I feel like the second fabric is definitely made to be more of like a compression fabric because it's very, it feels very thick."
		weight	heavy/not light (3)	MI	slowly fold back: "So like when she's moving, it would like fold and then it would take some time to fold back."
					Hold its form: "I also think that the fabric, this fabrics seems to be a little bit heavier than the first fabric because it if you look at the dancing avatar, you can see the fabric forms the shape when at the bottom of the pants. So it holds the form"

Subcategories	Sub-subcategories	Themes	Codes	Subcodes	Representative Quotes
				NMI	"I feel like it's like a heavier fabric than the one previously just because I feel like it takes more time to take its original shape back." "So I feel like it's a heavier like fabric. It'd be like better if you're doing like a hard duty kind of thing."
		possible fabric type	**not clothing fabric (2)**	NMI	"...it looks like the elasticity..." "...but kind of like tool where it's like, super, super light. And it like, you have to fold it to make it what you want it to be."
			Swimwear fabric	NMI	"Maybe for swimwear."
			Neoprene (2)	NMI	"I feel like this fabric kind of reminds me of like in neoprene."
		comfortability	not comfortable	MI	wirnkle: "Until like after I was like down here like the wrinkle on the back of her leg. It's very small. But for me, this seems not comfortable"
			possibly comfortable (4)	NMI	"...I feel like it could be comfortable."
		Emotional Expression	Negative	Weird (2)	"...that weird thing with the leg..." " I almost felt like the the physics of the world that this model was in was like underwater it was, it was very weird the way the fabric moved..."

F3:

Subcategories	Sub-subcategories	Themes	Codes	Subcodes	Representative Quotes
Description of how F3 looks and feels	Fabric appearance and performance	Flexibility	**flexible (7)**	MI	pull and bounce a lot: "It's super flexible, especially in like the first like, um, just fabric videos that it pulls a lot more and it kind of like, like bounces."

Subcategories	Sub-subcategories	Themes	Codes	Subcodes	Representative Quotes
					easy to crease and quickly release the crease: "I'd say like the way it creases and how quickly on creases itself ... Yeah, like the way it folds on itself when it's like pulled, like downward I guess. Like yeah with the flowyness mixed with like, the quickness that that like unfolds I guess." "...that's also make the fabrics three more kind of flexible and easier to have those creases."
				NMI	"That's a lot more comfortable and like flexible."
			conform with the body/move with the body (5)	MI	fold with the body and then unfold: "it just like it goes with your body, it folds with the body and then like unfolds once you like stand straight and it just looks like naturally like it's naturally moving"
			good recovery	MI	takes its shape back: "I like that, like it kind of goes with the movement of the body and then takes its shape back."
			good stretchability (5)	MI	not pulling: "it looks like in the crotch area. It looks more it didn't look like more like it's pulling." hold the form with resistance: "Yes, this fabric has more elasticity compared to the second one because when I looking at the fabric stretch it holds the form with resistance, which makes the crease."
			fair stretchability (2)	MI	struggle a bit when being pulled: "I also think that has a little bit less stretch to it than other ones do. And especially from like the stretch video, it seems like it was struggling a bit. Maybe this is just my textile brain going going and saying but I would love to know Like how much force at least if I was buying something, how much force is being put on something when it's being stretched." "...but it's not that really stretchability."

Subcategories	Sub-subcategories	Themes	Codes	Subcodes	Representative Quotes
			fluid	NMI	"It looks more comfortable and fluid."
		Drapability	**flowy (5)**	MI	flow: "you can tell like how like thin and like loose the fabric is just by like around the leg how easily it just kind of moves around and flows"
			good drape/drapery (3)	NMI	"(The moderator asked if everyone agreed so far F3 had the best drape and the most flexibility.) P4, P8: Yeah. Yes." "This one's more of a comfortable still and not very supportive but but very drapey."
		supportability	tight	NMI	"When I'm looking at the avatar it seems more much tighter than the fabric test and it looks more comfortable and fluid."
			loose	NMI	"You can tell like how like thin and like loose the fabric is..."
			soft	NMI	"...like around the leg how easily it just kind of moves around and flows."
			not supportive (3)	NMI	"...but I don't think it's it can be used as a sportswear or activewear because it's not kind of retaining the shapes and assist supporting..."
		Thickness	**thin (14)**	MI	bounce a lot: "Fabric three to me is much more thinner than fabric one because it bounces more than the fabric one."
				NMI	"So to know that notice that it must be a very very thin and very very lightweight fabric. I don't think cotton can make that thin." "Fabric three for me is too thin." "The fabric looks really thin."
		weight	light (3)	NMI	"It looks like more drapey and lightweight and thinner."

Subcategories	Sub-subcategories	Themes	Codes	Subcodes	Representative Quotes
			possibly light	NMI	"Um, it made me think that maybe had bigger spaces between the knit like stitches or something like that. This one feels like even though it's like, would be considered like a lightweight fabric. Maybe it still is more densely knit, like a jersey. It's the vibe I get."
			dense (2)	MI	drop downward after being pulled:"where it shows this fabric kind of like just like, drop at the very end. Because it shows at least I think that the fabric is more densely knit like that"
				NMI	"Maybe it still is more densely knit, like a jersey. It's the vibe I get."
		possible fabric type	knit jersey (3)	MI	hang in there a bit and just go down: "Compared to the other one where when it did that pull, it would just kind of like hang in there a little bit and like just go down. Um, it made me think that maybe had bigger spaces between the knit like stitches or something like that."
				NMI	"Maybe it still is more densely knit, like a jersey. It's the vibe I get."
			for daily wear/not for sportswear/T-shirt dress fabric/running top fabric (4)	NMI	"This is definitely will be something that I can wear in my daily life. Rather than I will wear this kind of fabric when I'm doing some sports."
		comfortability	**comfortable (10)**	NMI	"...it looks like more comfortable and stretchy." "...it looks more comfortable and fluid."
		Emotional Expression	Positive	natural/not weird/like/cute (7)	"So I feel like I like that because it's gonna be like, comfortable, natural, it's not gonna look weird and stuff like that. "

F4:

Subcategories	Sub-subcategories	Themes	Codes	Subcodes	Representative Quotes
Description of how F4 looks and feels	Fabric appearance and performance	Flexibility	Flexible	NMI	"...and this one it also looks super like kind of flexible."
			good stretchability (6)	MI	almost touch the ground and strongly bounce back: "fabric almost touching on the ground but it has the resistance to go back and bounce off. So it makes me to think about it is elastic. elastic and stretch. Stretchability."
					lay on the body: "I definitely think they're very similar in stretch and like how they lay on the body."
				NMI	"...it's also very stretchy but I feel like it takes a little bit more time to go back to its original shape." "It is stretchy. Yeah, it is stretchy."
			slow recovery	NMI	"... it takes a little bit more time to go back to its original shape."
			move with the body (2)	NMI	" But it takes a while to like respond to the movement like to move with the person a little bit."
			Not all-way stretch/stretchable (3)	MI	punch up at her hip: "Just like looking closely at the way that it like bunches up at her hips. It did not seem like this fabric had nearly as much stretch in it as the other ones did. "
			not conform the body (2)	NMI	"To me I definitely see the the other fabrics seem to kind of like conformed her body and give her another skin whereas this is like it doesn't go too wel"
		Drapability	Fairly drapey	MI	strongly bounce back and jiggle more: "it looks like it bounces back more than the ones we've seen, like that kind of jiggle at the end. It feels like it, it bounces back more, I think it might be like, in my brain ... it's still fairly drapey."
		supportability	slightly stiff	MI	wobble more, bounce more: " I almost think that fabric four is just a little bit stiffer because this one just seems to like wobble more or the other one like bounces more if that makes sense."

Subcategories	Sub-subcategories	Themes	Codes	Subcodes	Representative Quotes
			Possibly compressive	MI	draglines: "And I liked that this one seems like it could be somewhat compressive but still move with the body. Um, because it still has this draglines compared to like fabric to that didn't have any kind of draglines in it. "
			lack compression (3)	MI	wrinkle: "I noticed like wrinkles at the hip as well. And I did think that I learned a lot more like what be said about the tighter video but to me the wrinkling wasn't really like this is just how I interpreted it wasn't the stretch but more the lack of compression. So like it is stretchy enough to go over the person's body but maybe it's too much of a looser stretch to the point that it's creating those wrinkles. Because when you have like a garment that has compression, it's not conforming to the to the wrinkles in the body but rather like smashing it so it's all like the One flat skin piece. I don't know how to describe it. But I felt like this was like a looser kind of stretch to where it was like creating those draglines."
				NMI	"I prefer lots of compression in my garments. So that I just feel like nice and secure. But high stretches better for things like we were saying like yoga where you don't want you want to have a lot of mobility."
		Possible Fabric Type	**not for tight activewear/loose (6)**	NMI	"...and also it has very good stretch but maybe suitable for daily wear but not activewear" "Yeah, I definitely agree I think like he was saying I don't necessarily think the fabrics bad just in this application specifically for something that's tighter to the body. It probably will work better I think in in something looser, maybe like a an athletic jacket or like a rain jacket, something that's meant to be wicking but still warm."
		Thickness	**thin (5)**	MI	easy to wrinkle and fold: "I feel like this one might be thinner than number three, because I feel like it's easier to wrinkle and fold..." "And then like in the crotch area I was giving like a little bit of a camel toes I feel like it's like a very like easy to

Subcategories	Sub-subcategories	Themes	Codes	Subcodes	Representative Quotes
					fold."
					flow: "because of how like thin like I specifically look like around the leg and like to see how it folds and like flows"
				NMI	" ... when we were looking at the pulling it reminds me of like this is like a thinner fabric but it’s still like pretty heavy. "
		weight	**heavy/dense (7)**	MI	drop heavier and sudden bounces: "it’s like pretty dense because when we did the pulling like when it when you pulled it ... Yeah, like Yeah, like it like goes down like the first drop is like heavier and then it has two sudden like bounces after it."
					almost touch on the ground: "I I felt that this fabric is the heaviest fabric because this fabric was almost touching on the ground when you’re relaxing the fabric test."
				NMI	"... it’s like thin but if you like held fabric like much of it it’s like pretty dense" "...it’s just heavier by nature." "But it takes a while to like respond to the movement like to move with the person a little bit. So maybe it’s like kind of a heavier weight fabric. Like not in thickness, but just in the density."

F5:

Subcategories	Sub-subcategories	Themes	Codes	Subcodes	Representative Quotes
Description of how F5 looks and feels	Fabric appearance and performance	Flexibility	**stretchable/not all-way stretch (7)**	NMI	"It had like a good stretch, but it kind of like it didn't have much gives." "But it still was able to stretch, like a certain amount to where it wasn't like super stiff." "it seems to stretch more where it's attached to like the white things. Like and when it recovers it wrinkles." "I feel like if this was like on like a pair of leggings, it would like stretch at all of the same places and not where it needs to stretch which is like in the middle of the fabric because like if you play the clip again, it stretches more toward towards like the place it's being pulled from. So if it was on a on clothes, it wouldn't stretch where it needs to stretch it would stretch everywhere else."
			wrinkly/crinkly/creasy (8)	NMI	"it seems like very wrinkly." "And like there's so many crinkle going on." " ... it's like really crinkly but like if you were to make that into a dress it's like possible but then it would still wrinkled really badly..." "I thought it looked kind of like a crepe fabric like maybe a synthetic crepe, just because it it was thin and it had some drape, but it didn't have good retention." "I think this product if I compare it to other kinds of fabrics, it has like more wrinkles and we just find it shear." "I was able to find extra ease around waist in the tight fitting garment videos."
			bad shape retention (4)	MI	stick to the body, static: " I feel like the way like it's it sticks to the body it's got some sort of like static like it's just attracted to the body but like in

Subcategories	Sub-subcategories	Themes	Codes	Subcodes	Representative Quotes
					like the wrong places."
				NMI	" ...and then you see throughout the seams and then when it recovers, it'll be it'll be deformed in some way. Like when it recovers in the wrinkles and that's my problem with it."
			bad stretchability (7)	MI	little bounce: "But like when it came back, it didn't bounce as much as like the other ones had." "I think this one has the least elasticity because as the strength the pulling video it Yeah. As you can see like in the corner like when when it come back it doesn't bounce back." crease: "I feel like five is a fabric that can stretch but isn't made to be stretched because when I looked at the pulling for number five, the original position, there are no creases in it and after it, it stretched, there's creases at the top, so I feel like it's not made to stretch because, like, the more you stretch it the more it'll deform the fabric."
				NMI	"Because when the fabric is stretched, the middle part of the fabric is less tapered. So, it gives me the perception of less less elasticity..."
			not moving with the body/not conforming the body/not allowing easy movement (4)	NMI	"....this fabric is not that really conformable to the body." " I wouldn't want this in a full body garment just because I don't know if it would conform to the different crevices of the body as well "
		Drapability	slightly drapey	NMI	"I thought it looked kind of like a crepe fabric like maybe a synthetic crepe, just because it it was thin and it had some drape, but it didn't have good retention."

Subcategories	Sub-subcategories	Themes	Codes	Subcodes	Representative Quotes
		supportability	Stiff (2)	NMI	"I thought that this fabric looks stiffer..."
			compressive (2)	NMI	"(in the pulling video) it looks like if I were to like wrap that around something tightly like it would be very compressive" "I feel like it would be better used for like, like compressive garments because it's kind of stiff everywhere."
			loose/not tight (2)	NMI	" I feel like this fabric kind of and the stretches throwing me off because the way it looks like in this like looser fabric, it kind of looks like a nylon ripstop like the way it's moving."
		Thickness	**not thick/thin (7)**	MI	crease: "the fabric five it feels like a thinner so it can have more creases" edges roll and shrink: "So like I think the edge of the fabrics have some like little shrinkage and like roll over that. So to know that notice that it must be a very very thin and very very lightweight fabric."
				NMI	"I thought it looked kind of like a crepe fabric like maybe a synthetic crepe, just because it it was thin and it had some drape, but it didn't have good retention."
		weight	lightweight (3)	NMI	"t's more like a silk base like tencel or something like that very lightweight fabric."
		possible fabric type	**non woven/medical fabric/cheap fabric/band aid fabric/flimsy/synthetic crepe fabric/nylon ripstop (10)**	NMI	"For these, if I had to like, associate it with a fabric that I know like today, I would associate it with like medical scrubs." "When it's on the tighter garment then it's obviously not a ripstop"

Subcategories	Sub-subcategories	Themes	Codes	Subcodes	Representative Quotes
			cotton fabric (3)	NMI	"I will feel that fabric might be cotton, because it's more stiff and less stretchy and it feels like it might be on the like the yarn itself it might be on the center side. So it still can crease pretty easily but it's kind of stiff and trying to create those creases." "I think this fabric can be just 100% cotton fabrics. So it can be used for the T shirts." "I think it reminds me of cotton, this kind of fabric because for the loose jumpsuit one it has a lot for wrinkles."
			silk-like	NMI	"t's more like a silk base like tencel or something like that very lightweight fabric."
			not a cotton (2)	NMI	" I don't think it's a cotton because it has very lightweight and thin fabrics if you mentioned if you pull in that fabric so the edges of the fabric has shrinkage."
			jogger fabric	NMI	"but I think it looks like the kind of fabric that would be in like a pair of joggers or something like not something that's super tight fitting"
			not for activewear	NMI	"Comfortable to wear but not that ideal for activewear."
		comfortability	comfortable (2)	NMI	"You know, just comfortable T-shirts, but it's not that really stretchability." "Comfortable to wear but not that ideal for activewear."
		Emotional Expression	Negative	doesn't like it/weird (5)	"It folded really weird it was kind of like a cheap look like looking fabric." "And it just folded and crinkled really weird." "I don't like it at all."

F6:

Subcategories	Sub-subcategories	Themes	Codes	Subcodes	Representative Quotes
Description of how F6 looks and feels	Fabric appearance and performance	Flexibility	move with the body/allow good movement (2)	NMI	"It has a good stretch and with a good movement... it allows good movement ability for the wearers."
			good shape retention (2)	MI	go back to be straight: "this one has a little bit more of a structure where like, if you move left, the fabric will move left, but then kind of go back to being like straight."
			fair stretchability	NMI	"it had like a little bit of stretch as well"
			good stretchability (4)	NMI	"It like it has more elastic"
		Drapability	flowy (2)	NMI	"I think that this one is very flowy."
			Drapey	NMI	"I think this fabric seems very drape. And and I totally agree that it is a very good activewear fabric."
		supportability	Stiff	NMI	"And it's like... it has a little bit of stiffness."
			Loose	NMI	"It's like giving me the same sort of vibes and it's just like very loose and flowy."
			supportive (2)	MI	stick to the body without gapping or draping: "It almost felt like a swimwear fabric to me in a sense because of the way that it like almost stuck to the body and the tighter one and it didn't have a lot of gapping or draping or anything..."
		weight	**heavy/dense (4)**	MI	pulling down: "I feel like this fabric would be a little bit heavier than the other one. Because like in this like video, like the fabric is more kind of pulling down."
					flow, catch up the rest of the fabric, spin and keep going: "I would also say that fabric is a bit heavier. Just because of the way when it's flowing like at the bottom of the legs, like it almost looks like it's like going and then the rest of the fabric kind of catches up with it if that makes sense. Kind of like if

Subcategories	Sub-subcategories	Themes	Codes	Subcodes	Representative Quotes
					you’re spinning like long skirt and that like keeps going."
					thin folds: "But this one definitely has those like skinnier folds which leads me to believe maybe it’s a lighter weight fabric but still densely knit."
			light (3)	NMI	"...and then when it was in the looser outfit that draped one it had this it seemed very lightweight in the way that it it moved."
		possible fabric type	good for activewear (2)	NMI	" it seems really stretchy and quite good for active wear."
			synthetic/blend fabric (3)	MI	fold, slide out, don’t retain the draped look, thin folds: "I think the way that the drapes ... like the folds happened when the fabric stripping in this video kind of makes me think ... and this is like a long shot but kind of makes you can guess to synthetic fabric. Just because how they slide out and how they don’t really retain that draped look. Also how the the folds are like really thin and like close together."
			knit/jersey (3)	NMI	"... which leads me to believe maybe it’s a lighter weight fabric but still densely knit."
		comfortability	Comfortable	MI	not feel the seams go all the way: "(Before this sentence, the participant was saying the other fabric was not comfortable) but the way that it moves here seems really nicely like it stretches enough for it to not feel that seam go all the way around you if that makes sense."

Appendix B: Analysis of dimensions of visual comfort (restructured from Appendix A)

Theme 1: Flexibility

Sub-theme 1: Resilience			**Sub-theme 2: Stretchability**			**Sub-theme 3: conformability**		
Codes	Sub-codes	Representative quotes	Codes	Sub-codes	Representative quotes	Codes	Sub-codes	Representative quotes
Good shape retention	MI	**Bounce/Snap back easily:** "When I was watching the videos of it being pulled apart, I think it seemed like ... good retention ... Because it seems like it snaps back pretty easy, which is something that you would want in like athletic wear."	All-way stretch	MI	**Lay on the body pretty well**: "...it's able to stretch in a lot of different ways. And like it lays on the body pretty well"	**flexible(4)**	MI	**Soft creases/wrinkles move with the body**: "The creases to move with her body. It's not super stiff, you can see a lot of movement, even in the tighter fitting one. Like, as she moves like back and forth, you see wrinkles and it's just like it moves with the body really well."
good recovery	MI	**Strongly bounce back:** "But it looks like it had good recovery from the first video, like the bounce back seemed like very strong and easy to recover. "	**good stretchability (3)**	NMI	"I would say that it's got a good elasticity..."		NMI	"I would just gonna say it's really flexible. It's like, looks like a really flexible fabric..." "Looks like she's able to like move quite easily."
good recovery	MI	**goes with the movement and takes its shape back:** "I like that, like it kind of goes with the movement of the body and then takes its shape back."		MI	**Being pulled a little bit**: "(in the loose activewear video) Like at the bottom, it seems to be like pulling a bit, but that could indicate maybe like a stretch, going like vertically"	**flexible (7)**	MI	**pull and bounce a lot**: "It's super flexible, especially in like the first like, um, just fabric videos that it pulls a lot more and it kind of like, like bounces."

Sub-theme 1: Resilience			**Sub-theme 2: Stretchability**			**Sub-theme 3: conformability**		
Codes	Sub-codes	Representative quotes	Codes	Sub-codes	Representative quotes	Codes	Sub-codes	Representative quotes
good shape retention (2)	MI	**goes with the movement and go back to be straight:** "this one has a little bit more of a structure where like, if you move left, the fabric will move left, but then kind of go back to being like straight."	**good stretchability (5)**	MI	**not pulling**: "it looks like in the crotch area. It looks more it didn't look like more like it's pulling." hold the form with resistance: "Yes, this fabric has more elasticity compared to the second one because when I looking at the fabric stretch it holds the form with resistance, which makes the crease."			**easy to crease**: "I'd say like the way it creases and how quickly on creases itself ... Yeah, like the way it folds on itself when it's like pulled, like downward I guess. Like yeah with the flowyness mixed with like, the quickness that that like unfolds I guess." "...that's also make the fabrics three more kind of flexible and easier to have those creases."
slow recovery (7)	MI	**slowly undo itself:** "And then after a while it'll like undo itself. So like here, like it slowly undoes itself, but like takes a while."	**good stretchability (6)**	MI	**almost touch the ground and strongly bounce back**: "fabric almost touching on the ground but it has the resistance to go back and bounce off. So it makes me to think about it is elastic. elastic and stretch. Stretchability."		NMI	"That's a lot more comfortable and like flexible."
		stab, static, stick to the fabric itself: "So it kind of I feel like it's like stab like a static where it's like it's stuck to itself."			**lay on the body**: "I definitely think they're very similar in stretch and like how they lay on the body."	fluid	NMI	"It looks more comfortable and fluid."
		fabric hold its shape/position: "I also said like, it like holds its		NMI	"...it's also very stretchy but I feel like it takes a little bit more time to go	Flexible	NMI	"...and this one it also looks super like kind of flexible."

Sub-theme 1: Resilience			**Sub-theme 2: Stretchability**			**Sub-theme 3: conformability**		
Codes	Sub-codes	Representative quotes	Codes	Sub-codes	Representative quotes	Codes	Sub-codes	Representative quotes
		position or whatever the model does. And then it takes a while for it to do so like in the tight activewear when she like bends down, there's a wrinkle in the leg that holds its shape, and doesn't doesn't loosen itself up."			back to its original shape." "It is stretchy. Yeah, it is stretchy."			
		stick on to model: "So like in the first activewear the loose one, like the fabric would like stick onto the model after they turned. "	**good stretchability (4)**	NMI	"It like it has more elastic"	**conform with the body/move with the body (5)**	MI	**fold with the body and then unfold**: "it just like it goes with your body, it folds with the body and then like unfolds once you like stand straight and it just looks like naturally like it's naturally moving"
	NMI	"And even like in the first video where you would stretch it, you would stretch it and then like, it takes some time to go back down."	Stretchable (2)	MI	**Little up-and-down bounces, go down lower after turn back**: "When we were looking at the first clip the fabric to me looked heavy like it it's like heavy and elastic because like when you pull back it like bounces but it like doesn't like bounce up and down. It kind of goes down lower. So for me this looks heavy..."	move with the body (2)	NMI	" But it takes a while to like respond to the movement like to move with the person a little bit."

Sub-theme 1: Resilience			Sub-theme 2: Stretchability			Sub-theme 3: conformability		
Codes	Sub-codes	Representative quotes	Codes	Sub-codes	Representative quotes	Codes	Sub-codes	Representative quotes
slow recovery	NMI	"... it takes a little bit more time to go back to its original shape."		NMI	"I feel like it's like on the beach chairs that give it a sort of elasticity"	move with the body/allow good movement (2)	NMI	"It has a good stretch and with a good movement... it allows good movement ability for the wearers."
bad shape retention (3)	MI	**little bounce, hold/maintain its shape**: "Like it didn't really bounce back or anything. It kind of just held its own shape."	Stretchable	NMI	"...But that can still stretch."	**not moving with the body (5)**	MI	**stick on to the model:** "So like in the first activewear the loose one, like the fabric would like stick onto the model after they turned."
wrinkly/crinkly/creasy (8)	NMI	"it seems like very wrinkly." "And like there's so many crinkle going on." " ... it's like really crinkly but like if you were to make that into a dress it's like possible but then it would still wrinkled really badly..." "I thought it looked kind of like a crepe fabric like maybe a synthetic crepe, just because it it was thin and it had some drape, but it didn't have good retention." "I think this product if I compare it to other kinds	Stretchy	NMI	"...because it was like stretchy. And you could tell that the way it stretched."	not conform the body (2)	NMI	"To me I definitely see the the other fabrics seem to kind of like conformed her body and give her another skin whereas this is like it doesn't go too well"

Sub-theme 1: Resilience			Sub-theme 2: Stretchability			Sub-theme 3: conformability		
Codes	Sub-codes	Representative quotes	Codes	Sub-codes	Representative quotes	Codes	Sub-codes	Representative quotes
		of fabrics, it has like more wrinkles and we just find it shear." "I was able to find extra ease around waist in the tight fitting garment videos."						
bad shape retention (4)	MI	**stick to the body, static**: " I feel like the way like it's it sticks to the body it's got some sort of like static like it's just attracted to the body but like in like the wrong places."	fair stretchability (2)	MI	**struggle a bit when being pulled**: "I also think that has a little bit less stretch to it than other ones do. And especially from like the stretch video, it seems like it was struggling a bit. Maybe this is just my textile brain going going and saying but I would love to know Like how much force at least if I was buying something, how much force is being put on something when it's being stretched." "...but it's not that really stretchability."	not moving with the body/not conforming the body/not allowing easy movement (4)	NMI	"....this fabric is not that really conformable to the body." " I wouldn't want this in a full body garment just because I don't know if it would conform to the different crevices of the body as well "

Sub-theme 1: Resilience			Sub-theme 2: Stretchability			Sub-theme 3: conformability		
Codes	Sub-codes	Representative quotes	Codes	Sub-codes	Representative quotes	Codes	Sub-codes	Representative quotes
	NMI	" ...and then you see throughout the seams and then when it recovers, it'll be it'll be deformed in some way. Like when it recovers in the wrinkles and that's my problem with it."	**stretchable/not all-way stretch (7)**	NMI	"It had like a good stretch, but it kind of like it didn't have much gives." "But it still was able to stretch, like a certain amount to where it wasn't like super stiff." "it seems to stretch more where it's attached to like the white things. Like and when it recovers it wrinkles." "I feel like if this was like on like a pair of leggings, it would like stretch at all of the same places and not where it needs to stretch which is like in the middle of the fabric because like if you play the clip again, it stretches more toward towards like the place it's being pulled from. So if it was on a on clothes, it wouldn't stretch where it needs to stretch it would stretch everywhere else."			
			fair stretchability	NMI	"it had like a little bit of stretch as well"			

Sub-theme 1: Resilience			**Sub-theme 2: Stretchability**			**Sub-theme 3: conformability**		
Codes	Sub-codes	Representative quotes	Codes	Sub-codes	Representative quotes	Codes	Sub-codes	Representative quotes
			Not all-way stretch/stretchable (3)	MI	**punch up**: "Just like looking closely at the way that it like bunches up at her hips. It did not seem like this fabric had nearly as much stretch in it as the other ones did. "			
			bad stretchability (7)	MI	**little bounce**: "But like when it came back, it didn't bounce as much as like the other ones had." "I think this one has the least elasticity because as the strength the pulling video it Yeah. As you can see like in the corner like when when it come back it doesn't bounce back." **crease:** "I feel like five is a fabric that can stretch but isn't made to be stretched because when I looked at the pulling for number five, the original position, there are no creases in it and after it, it stretched, there's creases at the top, so I feel like it's not made to stretch because, like, the more you stretch it the more it'll deform the fabric."			

Sub-theme 1: Resilience			Sub-theme 2: Stretchability			Sub-theme 3: conformability		
Codes	Sub-codes	Representative quotes	Codes	Sub-codes	Representative quotes	Codes	Sub-codes	Representative quotes
				NMI	"Because when the fabric is stretched, the middle part of the fabric is less tapered. So, it gives me the perception of less less elasticity..."			

Theme 2: Drapability

Codes	Sub-codes	Representative quotes
good flow (2)	NMI	"..it's got like a good flow."
Good drape	NMI	"And then in the video of the looser jumpsuit, I think it had like a pretty decent drape to it..."
flowy (5)	MI	**flow:** "you can tell like how like thin and like loose the fabric is just by like around the leg how easily it just kind of moves around and flows"
good drape/drapery (3)	NMI	"(The moderator asked if everyone agreed so far F3 had the best drape and the most flexibility.) P4, P8: Yeah. Yes." "This one's more of a comfortable still and not very supportive but but very drapey."
flowy (2)	NMI	"I think that this one is very flowy."
Drapey	NMI	"I think this fabric seems very drape. And and I totally agree that it is a very good activewear fabric."
Fairly drapey	MI	**strongly bounce back and jiggle more:** "it looks like it bounces back more than the ones we've seen, like that kind of jiggle at the end. It feels like it, it bounces back more, I think it might be like, in my brain ... it's still fairly drapey."
slightly drapey	NMI	"I thought it looked kind of like a crepe fabric like maybe a synthetic crepe, just because it it was thin and it had some drape, but it didn't have good retention."
not flowy (3)	NMI	"... it could be and it's not made to be loose and flowy"

Theme 3: Supportability

Codes	Sub-codes	Representative quotes
Tight (2)	MI	**Being pulled a little bit:** "I think for me, it’s the crotch area to the top seems too tight, which is why it’s creating the creases but that might just be me being picky with it."
tight	NMI	"When I’m looking at the avatar it seems more much tighter than the fabric test and it looks more comfortable and fluid."
Stiff (2)	NMI	"I thought that this fabric looks stiffer..."
Stiff (6)	NMI	"I don’t know or like a like a double knit cotton something that’s like, has pretty, like stiff qualities to it." "...it has like a lot of structure to it."
Stiff	NMI	"And it’s like... it has a little bit of stiffness."
slightly stiff	MI	**wobble more, bounce more:** " I almost think that fabric four is just a little bit stiffer because this one just seems to like wobble more or the other one like bounces more if that makes sense."
compressive/supportive (7)	MI	**hold/maintain its shape**: "but I think it has good compression in terms of maintaining the shape"
	NMI	"I feel like the second fabric is definitely made to be more of like a compression fabric because it’s very, it feels very thick." "But it looks really compressive or it could be and it’s not made to be loose and flowy." "I’m not saying it’s not comfortable to wear but I feel like it’d be more of like, like for like a supportive garment or something that provides more compression when you’re working out instead of something made to be light and flowy. "
compressive (2)	NMI	"(in the pulling video) it looks like if I were to like wrap that around something tightly like it would be very compressive" "I feel like it would be better used for like, like compressive garments because it’s kind of stiff everywhere."
supportive (2)	MI	**stick to the body without gapping or draping**: "It almost felt like a swimwear fabric to me in a sense because of the way that it like almost stuck to the body and the tighter one and it didn’t have a lot of gapping or draping or anything..."

Codes	Sub-codes	Representative quotes
not wrinkly (3)	MI	**no draglines:** "It doesn't really. Like there's no draglines or like, you know."
Possibly compressive	MI	**some draglines**: "And I liked that this one seems like it could be somewhat compressive but still move with the body. Um, because it still has this draglines compared to like fabric to that didn't have any kind of draglines in it. "
slightly soft	NMI	"It looks a little bit soft, but I can't really tell."
loose/not tight (4)	MI	**gapping:** "... this one can like it's not very clear to see your body shape." "It kind of looks like in the back there, there might be like some, like gapping between her back and the fabric."
loose/not tight (2)	NMI	" I feel like this fabric kind of and the stretches throwing me off because the way it looks like in this like looser fabric, it kind of looks like a nylon ripstop like the way it's moving."
not for tight activewear/loose (6)	NMI	"...and also it has very good stretch but maybe suitable for daily wear but not activewear" "Yeah, I definitely agree I think like he was saying I don't necessarily think the fabrics bad just in this application specifically for something that's tighter to the body. It probably will work better I think in in something looser, maybe like a an athletic jacket or like a rain jacket, something that's meant to be wicking but still warm."
Loose	NMI	"It's like giving me the same sort of vibes and it's just like very loose and flowy."
loose	NMI	"You can tell like how like thin and like loose the fabric is..."
Soft (4)	NMI	"Yeah, on the tight one. You can. I feel like it looks softer. Like kind of, like the Lululemon fabric that's really soft." "I think this fabric looks much more softer because maybe I can see little of the texture on the fabric...like knit jersey texture"
soft	NMI	"...like around the leg how easily it just kind of moves around and flows."
Not compressive	NMI	" I will feel it will be comfortable to wear in your body. It will not be very tight and it will not give you pressure."
not supportive (3)	NMI	"...but I don't think it's it can be used as a sportswear or activewear because it's not kind of retaining the shapes and assist supporting..."

Codes	Sub-codes	Representative quotes
lack compression (3)	MI	**wrinkle**: "I noticed like wrinkles at the hip as well. And I did think that I learned a lot more like what be said about the tighter video but to me the wrinkling wasn't really like this is just how I interpreted it wasn't the stretch but more the lack of compression. So like it is stretchy enough to go over the person's body but maybe it's too much of a looser stretch to the point that it's creating those wrinkles. Because when you have like a garment that has compression, it's not conforming to the to the wrinkles in the body but rather like smashing it so it's all like the One flat skin piece. I don't know how to describe it. But I felt like this was like a looser kind of stretch to where it was like creating those draglines."
	NMI	"I prefer lots of compression in my garments. So that I just feel like nice and secure. But high stretches better for things like we were saying like yoga where you don't want you want to have a lot of mobility."

Theme 4: Weight

Codes	Sub-codes	Representative quotes
Heavy weight (2)	MI	**Little up-and-down bounces, go down lower after turn back:** "When we were looking at the first clip the fabric to me looked heavy like it it's like heavy and elastic because like when you pull back it like bounces but it like doesn't like bounce up and down. It kind of goes down lower. So for me this looks heavy..."
	NMI	" ... it just looks like a heavier fabric (in the fabric videos)."
heavy/not light (3)	MI	**slowly fold back**: "So like when she's moving, it would like fold and then it would take some time to fold back."
		Hold its form: "I also think that the fabric, this fabrics seems to be a little bit heavier than the first fabric because it if you look at the dancing avatar, you can see the fabric forms the shape when at the bottom of the pants. So it holds the form"
	NMI	"I feel like it's like a heavier fabric than the one previously just because I feel like it takes more time to take its original shape back." "So I feel like it's a heavier like fabric. It'd be like better if you're doing like a hard duty kind of thing."

Codes	Sub-codes	Representative quotes
dense (2)	MI	**drop downward** after being pulled:"where it shows this fabric kind of like just like, drop at the very end. Because it shows at least I think that the fabric is more densely knit like that"
	NMI	"Maybe it still is more densely knit, like a jersey. It's the vibe I get."
heavy/dense (7)	MI	**drop heavier and sudden bounces**: "it's like pretty dense because when we did the pulling like when it when you pulled it ... Yeah, like Yeah, like it like goes down like the first drop is like heavier and then it has two sudden like bounces after it."
		almost touch on the ground: "I I felt that this fabric is the heaviest fabric because this fabric was almost touching on the ground when you're relaxing the fabric test."
	NMI	"... it's like thin but if you like held fabric like much of it it's like pretty dense" "...it's just heavier by nature." "But it takes a while to like respond to the movement like to move with the person a little bit. So maybe it's like kind of a heavier weight fabric. Like not in thickness, but just in the density."
heavy/dense (4)	MI	**pulling down**: "I feel like this fabric would be a little bit heavier than the other one. Because like in this like video, like the fabric is more kind of pulling down."
		flow, catch up the rest of the fabric, spin and keep going: "I would also say that fabric is a bit heavier. Just because of the way when it's flowing like at the bottom of the legs, like it almost looks like it's like going and then the rest of the fabric kind of catches up with it if that makes sense. Kind of like if you're spinning like long skirt and that like keeps going."
		thin folds: "But this one definitely has those like skinnier folds which leads me to believe maybe it's a lighter weight fabric but still densely knit."
Medium weight (2)	MI	**held down by gravity**: "...it actually seemed like maybe it was like a midweight fabric because of the way it kind of like is held down by gravity."
		Not pleating, thick folds move with the body: "And the way that the almost it's not pleating, but the way the like the folds are kind of moving around. They're there I'm trying to find the best word for this. The folds are thicker..."
	NMI	"...but then the second one and the third one on the fabrics (the twisting and sliding videos), they start to look lighter just based on the twisting."

<table>
<tr><th>Codes</th><th>Sub-codes</th><th>Representative quotes</th></tr>
<tr><td>lightweight (3)</td><td>NMI</td><td>"t’s more like a silk base like tencel or something like that very lightweight fabric."</td></tr>
<tr><td>Light weight (2)</td><td>NMI</td><td>"But then on the model, it looked much more light and it looked more like like active wear on the models..."</td></tr>
<tr><td>light (3)</td><td>NMI</td><td>"It looks like more drapey and lightweight and thinner."</td></tr>
<tr><td>possibly light</td><td>NMI</td><td>"Um, it made me think that maybe had bigger spaces between the knit like stitches or something like that. This one feels like even though it’s like, would be considered like a lightweight fabric. Maybe it still is more densely knit, like a jersey. It’s the vibe I get."</td></tr>
</table>

Theme 5: Thickness

<table>
<tr><th>Codes</th><th>Sub-codes</th><th>Representative quotes</th></tr>
<tr><td>thick (4)</td><td>NMI</td><td>"I feel like the second fabric is definitely made to be more of like a compression fabric because it’s very, it feels very thick."</td></tr>
<tr><td rowspan="2">thin (14)</td><td>MI</td><td>bounce a lot: "Fabric three to me is much more thinner than fabric one because it bounces more than the fabric one."</td></tr>
<tr><td>NMI</td><td>"So to know that notice that it must be a very very thin and very very lightweight fabric. I don’t think cotton can make that thin."
"Fabric three for me is too thin."
"The fabric looks really thin."</td></tr>
<tr><td rowspan="3">thin (5)</td><td rowspan="2">MI</td><td>easy to wrinkle and fold: "I feel like this one might be thinner than number three, because I feel like it’s easier to wrinkle and fold..." "And then like in the crotch area I was giving like a little bit of a camel toes I feel like it’s like a very like easy to fold."</td></tr>
<tr><td>flow: "because of how like thin like I specifically look like around the leg and like to see how it folds and like flows"</td></tr>
<tr><td>NMI</td><td>" ... when we were looking at the pulling it reminds me of like this is like a thinner fabric but it’s still like pretty heavy. "</td></tr>
</table>

Codes	Sub-codes	Representative quotes
not thick/thin (7)	MI	**crease:** "the fabric five it feels like a thinner so it can have more creases" edges roll and shrink: "So like I think the edge of the fabrics have some like little shrinkage and like roll over that. So to know that notice that it must be a very very thin and very very lightweight fabric."
	NMI	"I thought it looked kind of like a crepe fabric like maybe a synthetic crepe, just because it it was thin and it had some drape, but it didn't have good retention."

Theme 6: Comfortability

Codes	Sub-codes	Representative quotes
Comfortable	NMI	"I will feel it will be comfortable to wear in your body."
comfortable (10)	NMI	"...it looks like more comfortable and stretchy." "...it looks more comfortable and fluid."
comfortable (2)	NMI	"You know, just comfortable T-shirts, but it's not that really stretchability." "Comfortable to wear but not that ideal for activewear."
Comfortable	MI	**not feel the seams go all the way**: "(Before this sentence, the participant was saying the other fabric was not comfortable) but the way that it moves here seems really nicely like it stretches enough for it to not feel that seam go all the way around you if that makes sense."
possibly comfortable (4)	NMI	"...I feel like it could be comfortable."
Not comfortable	NMI	"I think if I'm looking solely on the fabric, it doesn't look comfortable."
not comfortable	MI	**wirnkle**: "Until like after I was like down here like the wrinkle on the back of her leg. It's very small. But for me, this seems not comfortable"

Theme 7: possible fabric type

Codes	Sub-codes	Representative quotes
Beach chair fabric (2)	NMI	"I feel like it's like on the beach chairs that give it a sort of elasticity. But like you can let water like go through I feel like you've been swimming."
Activewear fabric/good for activewear (3)	MI	Bounce/Snap back easily: "Because it seems like it snaps back pretty easy, which is something that you would want in like athletic wear."
	NMI	"But then on the model, it looked much more light and it looked more like like active wear on the models..."
man-made/synthetic/blend fabric (3)	NMI	"I think it is a little manmade. It is not the like a cotton that is very soft and stretchy..."
Rayon fabric (2)	NMI	"I guess a rayon." "I could definitely agree with the the rayon guess."
Woven denim	NMI	" ...if I look at the fabric stretch test, I see the surface roughness clearly, it looks like woven denim texture … a little lighter woven, woven denim."
not clothing fabric (2)	NMI	"...it looks like the elasticity..." "...but kind of like tool where it's like, super, super light. And it like, you have to fold it to make it what you want it to be."
Swimwear fabric	NMI	"Maybe for swimwear."
Neoprene (2)	NMI	"I feel like this fabric kind of reminds me of like in neoprene."
knit jersey (3)	MI	hang in there a bit and just go down: "Compared to the other one where when it did that pull, it would just kind of like hang in there a little bit and like just go down. Um, it made me think that maybe had bigger spaces between the knit like stitches or something like that."
	NMI	"Maybe it still is more densely knit, like a jersey. It's the vibe I get."
for daily wear/not for sportswear/T-shirt dress fabric/running top fabric (4)	NMI	"This is definitely will be something that I can wear in my daily life. Rather than I will wear this kind of fabric when I'm doing some sports."

Codes	Sub-codes	Representative quotes
non woven/medical fabric/cheap fabric/band aid fabric/flimsy/synthetic crepe fabric/nylon ripstop (10)	NMI	"For these, if I had to like, associate it with a fabric that I know like today, I would associate it with like medical scrubs." "When it's on the tighter garment then it's obviously not a ripstop"
cotton fabric (3)	NMI	"I will feel that fabric might be cotton, because it's more stiff and less stretchy and it feels like it might be on the like the yarn itself it might be on the center side. So it still can crease pretty easily but it's kind of stiff and trying to create those creases." "I think this fabric can be just 100% cotton fabrics. So it can be used for the T shirts." "I think it reminds me of cotton, this kind of fabric because for the loose jumpsuit one it has a lot for wrinkles."
silk-like	NMI	"t's more like a silk base like tencel or something like that very lightweight fabric."
not a cotton (2)	NMI	" I don't think it's a cotton because it has very lightweight and thin fabrics if you mentioned if you pull in that fabric so the edges of the fabric has shrinkage."
jogger fabric	NMI	"but I think it looks like the kind of fabric that would be in like a pair of joggers or something like not something that's super tight fitting"
not for activewear	NMI	"Comfortable to wear but not that ideal for activewear."
good for activewear (2)	NMI	" it seems really stretchy and quite good for active wear."
synthetic/blend fabric (3)	MI	fold, slide out, don't retain the draped look, thin folds: "I think the way that the drapes ... like the folds happened when the fabric stripping in this video kind of makes me think ... and this is like a long shot but kind of makes you can guess to synthetic fabric. Just because how they slide out and how they don't really retain that draped look. Also how the the folds are like really thin and like close together."
knit/jersey (3)	NMI	"... which leads me to believe maybe it's a lighter weight fabric but still densely knit."

Appendix C: Comparisons of contrasting virtual fabric pairs

		F1: "Stretch and Shear Low"	F5: "Stretch and Shear High"
Overall impression		Comfortable fabric good for activewear	a non-durable, lower-quality material
Feature visual-tactile attributes (high frequency codes)		flexible, soft, good stretchability	wrinkly/crinkly/creasy, bad stretchability, stretchable but not all-way stretch, not thick/thin
Feature dimensions of visual comfort (themes indicated by high frequency codes)		**high flexibility, low supportability**	**low flexibility, thin**
Descriptions keywords about the fabric movements (MI contents describing feature visual-tactile attributes)	bouncing (in fabric pulling test simulation)	"Bounce/Snap back easily"	"little bounce"
	compatibility with the body movement (in tight and loose activewear simulation)	"Lay on the body pretty well", "Soft creases/wrinkles move with the body"	"crease", "edges roll and shrink"
degree of liking		neutral	Negative

		F4: "Bending Low"	F2: "Bending High"
Overall impression		a comfortable fabric for daily wear, but not for tight activewear	Not like typical clothing fabric, like rubber or swinwear fabric
High frequency codes		heavy/dense, good stretchability, thin	slow recovery, compressive/supportive, stiff, not moving with the body
Dimensions indicated by the high frequency codes		**high flexibility, heavy, thin**	**low flexibility, high supportability**
Descriptions keywords about the fabric movements	bouncing (in fabric pulling test simulation)	"almost touch the ground and strongly bounce back", "drop heavier and sudden bounces", "wobble more, bounce more", "strongly bounce back and jiggle more"	"bounce back strongly", "little bounce, hold/maintain its shape"
	gapping (in tight and loose activewear simulation)	"puching up at her hip"	"stick to the body"

		F4: "Bending Low"	F2: "Bending High"
	wrinkling (in tight and activewear simulation)	"draglines", "wrinkling"	"no draglines"
	compatibility with the body movement (in tight and loose activewear simulation)	"lay on the body"	"hold its shape/form", "slowly undo itself", "stick to the model", "slowly fold back"
degree of liking		neutral	Negative

		F3: "Density Low"	F6: "Density High"
Overall impression		A comfortable fabric good for daily wear, but not for activewear especially high-impact sports	a synthetic fabric good for activewear
High frequency codes		thin, comfortable, flexible, conforming with the body/moving with the body, flowy, good stretchability	heavy, good stretchability, light
Dimensions indicated by the high frequency codes		**high flexibility, high drapability, low supportability, thin (and light)**	**high flexibility, heavy**
Descriptions keywords about the fabric movements	large or strong bouncing (in fabric pulling test simulation)	"bounce a lot"	"pulling down"
	flowing (in loose activewear video)	"flow", "unfold mixed with flowyness"	"go back to straight", "catch up the rest of the fabric, spin and keep going"
	compatibility with the body movement (in tight and loose activewear simulation)	"goes with the body and then take its shape back", "not pulling"	"stick to the body without gapping or draping"
	short-lived or thin folds	"quickly crease and uncrease, fold and unfold"	"thin folds close to each other", "skinny folds"
degree of liking		Positive	neutral

Appendix D: Comparison of the six virtual fabrics

	Comparison	Best & worst comfort
F1: "Stretch and Shear Low"	N/A	**Most comfortable:** **[P8] Appropriate flowyness, stretchability, weight, drape and quality** **[P2-2] F1 is good for doing light-impact activities.** **[P4-2]**
F2: "Bending High"	[P2] stiffer [P7, P8] more compressive, thicker, heavier [P3] heavier, less mobility, less fluid [P6] produced by thicker yarn, so less wrinkly [P4-2] less wrinkly, have stronger fibers [P2-2] stiffer, more supportive [P2-2] less comfortable	**The best compression:** **[P8]** **[P1-2]** **Least comfortable:** **[P6] thick, bringing a sense of preventing heat from dissipating from the body, also not sweat-wicking** **[P7-2, P3-2]** **[P6-2] thick, heavy**
F3: "Density Low"	[P5] the thinnest among F1-F3 [P7] the thinnest, the lightest among F1-F3 [P3] more elastic than F2 [P1] less wrinkly than F1, worse drape than F1 since F3 is too thin [P6] F1 may have a higher modulus than F3, so F3 is more flexible and easier to crease. [P3-2] the thinnest among F1-F3, less stretchier than F1 and F2 [P6-2, P5-2] similar to F1, lighter than F2 [P1-2] thinner than F1 [P3-2] similar to F1, more recovery and stretchability compared to F1 [P7-1] More drapey than F1	

	Comparison	Best & worst comfort
F4: “Bending Low”	[P5, P1] similar to F3 [P7] might be thinner than F3 [P3] similar to F2 in weight, stretchier than F2 [P2] similar to F1, slightly stiffer than F1, slightly lighter than F1 [P7-2] “the middle ground between F1 and F3 maybe where it’s still fairly drapey” [P5-2] similar to F1 and F3	**Most comfortable:** **[P7-2]**
F5: “Stretch and Shear High”	[P5] Less stretchy than F1, F3 and F4, stretchier than F2 [P4] the least stretchability [P8] Stiffness and stretch of F2 are more consistent than F5. F2 is stiffer than F5. F5 is stretchier than F2 but the stretch is not consistent. [P6] Compared to F2, F5 has more creases, making it look not sticky if the wearer is sweating. F2 is less stretchier, F2 looks thicker like a fabric with siding or coating. [P5-2]Compared to F5, F2 has a softer surface texture similar to sweatshirt fabric, and is not super slinky. [P6-2] less stretchier than F1, F3 and F4	**Least comfortable:** **[P8]bad stretchability and shape recovery** **[P2, P5] “make me mad”** **[P1-P8 except for P6] don’t like it** **[P3-2] Bad stretchability** **[P5-2] stick to the torso** **[P4-2] It wrinkles and shrinks a lot.** **[P1-2] “don’t use that”** **Acceptable comfort:** **[P2-2] “I think it will be comfortable but I will also not gonna wearing this, this kind of fabric out of the house”**
F6: “Density High”	[P2, P4] heavier than F4 and F5 [P2] similar to F1 [P2-2] F6 is slightly more supportive than F1.	**Most comfortable:** **[P2] the best drape (indicated from the little folds around the leg), appropriate thickness, soft** **[P3-2, P5-2] allowing ease of movement, appropriate compression and drape** **[P2-2] F6 is more supportive so it is good for higher impact sports.**

Appendix E: Full quotes of Content Area 3, Comments and suggestions on Simulations

Codes of comments	Codes of suggestions	Quotes	Speaker
hard to correlate fabric test and activewear videos since the fabric test one looks heavier		So somehow for me I'm kind of having a hard time to correlate with the fabric test and the avatar movements.	P3
		(Mod: Gotcha. You meet the fabric test will looks heavier) Little bit.	P3
movement in tight activewear video not big enough to see stretchability		I have one comment about the tight fitting clothing simulation on the model, I would what like like to see if a bigger movement can be done for the model like bending all over to like, bending over to reach the ground, that kind of movement, like this type of movement. It's not like stretching or bend the fabric as much. So when it's tight fitting It seems like all of them having a certain type of like, certain degree of extent stretchability and may not see a such a big difference with this, this amount of movement.	P6
	bigger movements are needed for tight activewear video, to discover dynamic fit.	I think it would be as far as like posing goes, I think it'd be interesting to see how, like the fabric fit if it was just like a pair of leggings or something and they bent over and how that recovery would happen. If it would like stay in the same place or been pulled down. I think that'd be interesting to see.	P2
	bigger movements are needed for tight activewear video.	We need a squat.	P8
the texture feature when fabric being distorted as activewear not visible enough		Um, I would say I know, it's really difficult to do like 3d modeling. But it could be possible to like change the fabric, like the type of fabric that's being used to demonstrate what fabric you're trying to replicate. Because I, if if I'm not mistaken, all the fabrics were visually the same. They just had different elasticities to them and different stretch abilities, which I think for me it it hindered my ability to guess because I'm looking at like, Oh, is it like a woven? Is it knitted is it like non woven, but because they're all the same i, i My brain is like tricking me into thinking that they're all like woven or knitted, even though they may not be in terms of when you're going to replicate it into the real world. So it would be nice to be able to see, like close ups of the fabric you're trying to replicate.	P1

Codes of comments	Codes of suggestions	Quotes	Speaker
not sure about how color would affect one’s perception	have a close up to see the fabric details on activewear	I feel like going along with P1. Like if we have like a little close up or like a small video of like, the fabric itself, it would be like better to judge Oh, like this fabric is better or whatever. And also like the color of the fabric I feel like would really affect how it looks on a person.	P7
the texture feature (especially the optical feature) when fabric being distorted as activewear not visible enough		That and also how thin it is because for me if I do active wear, I would not like it to be see through. So I mean obviously the fabrics on the models cover them, but like if you’re stretching or if you’re like bending forward, I know that when some fabrics are stretched they need more see through and that’s like really annoying to deal with. So that like with the squat test or like the bending over test just to see if you know you have to wear specific colors underneath the garment to make sure that you’re not like exposing yourself that’d be nice too.	P1
	use virtual fabric with printed patterns to magnify the texture feature when fabric being distorted	I have another thing I think it could be helpful to put like a pattern on it to see how the pattern stretches and if that would be like distorted or not.	P8
the texture feature when fabric being distorted as activewear not visible enough		Yeah, because when I when I, I mean, when you showed them to us I was at the beginning, I was looking really intensely at like, the structure of it. But then after a while I realized I think they were all like the same or they were close to the same that at some point, I was like, I actually shouldn’t be watching what I think the material is made out of, because then my brain is going to tell me like, Oh, if it’s like, something, if it’s caught, it’s supposed to look this way. Or if it’s supposed to be like tool, it’s supposed to look this way, or like something heavy. So I stopped looking at the structure for a while, or like how it’s supposed to look. Yeah, but yeah, I think, because that really does affect or for me, at least, it affects the way I look at the fabric, because there are some where it’s like, oh, this reminds me of a specific fabric. And I’m going to assume that all the fabric that’s being used in you know, fabric one is made out of this, and I’ll be like, Oh, for me, that’s not like active wear material. And that, you know, makes me a little biased.	P1
	A scale is needed in fabric test video	Oh, and for these tests video, like the fabric test videos, I would prefer if there is like something to like to compare with a scale or like a scale bar to show because, like for the stretch ability test, if there’s nothing to compare with, it’s hard to imagine which one is extend better. Let’s say like between fabric one and three,	P6

Codes of comments	Codes of suggestions	Quotes	Speaker
		they... when you looking at them that together. And as they’re so fast, it’s so hard to tell which one is more elastic.	
movement in activewear video not big enough to see stretchability		When it comes to the dancing I felt like the movements were especially if this is being used in athletic wear, I felt the movements in that dance specifically were a little tame because I’m thinking like for things like yoga or if I’m if I’m buying yoga pants or a jumpsuit, I want to know if the fabric is going to get more see through when I bend over that kind of stuff. And it didn’t feel like she was making any big movement.	P3-2
hard to tell stretchability from the fabric test videos		I think that was it gave me more of a sense of the structure if that makes sense and the way that it stretches because especially with the videos you can’t really tell how the stretches as...	P3-2
hard to tell stretchability from the fabric test videos		I agree with that. Rather than looking at this video, I’m checking the garment simulation on an avatar helps me to gain an idea of the weight or like dragness or elasticity or flowing is of the fabric. That is useful for observing the garment.	P6-2
the tight activewear video has not enough wrinkle/folds details to be trustable		I think I can tell more about the fabric on the looser jumpsuit video than in the tight one. Just because on the tight one, like on a real person, you’d be able to see like dimples in the skin or like just the texture of the skin kind of and I feel like on an avatar doesn’t have those like really specific like folds and wrinkles and things like that. So I don’t know I feel like personally I wouldn’t trust what it looks like tight on an avatar.	P7-2
the loose activewear is better to tell fabric texture			
the loose activewear is better to evaluate fabric		yeah, no, I definitely agree with the tighter outfit. I if you took that video and the video from before, I probably wouldn’t be able to tell you the difference from them. The difference between them like which fabric was which, but the looser outfit definitely told me a lot.	P3-2
the tight activewear video has not enough wrinkle/folds details to be trustable			

Codes of comments	Codes of suggestions	Quotes	Speaker
hard to tell fabric content through the videos		I am personally having a hard time with like, without knowing the fiber content or like anything that I'm having a hard time making like a decision of whether or not I would think it'd be comfortable because like, I have a background in textiles so I can tell like what kind of drape to look for and like what weight that might like cue me to think of what the fabric is but like without showing ...	P5-2
	A scale is needed in fabric test video the texture feature (especially the optical feature) when fabric being distorted as activewear needs to be visible	Or maybe how big this swatch is, because I think it can tell you a lot about the weight, if that makes sense. And then I think I mentioned this before, but I think the biggest thing that I'm missing with these is how the opacity works. Because on a real life model, if you see a video of them bending down, and then you see their underwear, then you can tell how that's going to fit you. Whereas with this, because it's simulated, it does, I don't know if it has the capabilities to show you the opacity when someone bends or that makes sense, because I think that's what this video right here could be showing you is, doesn't have that property, if that makes sense. Like it would be a very helpful video to to have like that tight fitting garment.	P3-2
hard to tell fabric content through the videos hard to evalute from tight activewear video		I'm sorry, I still I think I personally as a consumer, just have a hard time with the visuals like this, where the cues are so like minut and if I think about it from a perspective of somebody who doesn't, like have a background in like materials, and like really kind of think about the way that they move in depth in the way that a lot of us have. It wouldn't do too much for me. So, like especially for the tight fitting garments. I just have trouble figuring out anything out of it	P5-2
the loose activewear is better to evaluate fabric		Yeah, definitely. And for this experience, like it's been with all the fabrics, but the looser garment I think shows a lot more just based off of what I would like being able to see on a body helps a ton. And when it's so much easier to tell.	P5-2
the fabric pulling video is helpful to identify fabric stretchability		I think the pulling video mostly helped me to identify the differences between different fibers. Yeah, so yeah, I can clearly from the videos to see how stretchy the fabric is.	P2-2

Codes of comments	Codes of suggestions	Quotes	Speaker
	use virtual fabric with printed patterns to magnify the texture feature when fabric being distorted	I think also the like the pulling sliding twisting videos, I think it might help me more if there was a print on it. Maybe because you know, like on athletic wear, like sometimes just a print and then when it stretches out getting like, see through or distorted or, or that kind of thing. I know that the Grays the best to see drape lines like in like the avatars like it helps me see it more clearly. That maybe I'm dude, if I had a print on it, you'd be able to tell the stretch more.	P7-2
	use virtual fabric with printed patterns to magnify the texture feature when fabric being distorted, which is a good indicator of scale	I also think a print could help me understand like the scale of it. Because if this fabric was like the swatch was two by two versus 24 by 24 I think that the fabric will feel a lot different if it had those properties, if that makes sense...And so it kind of helps me understand the scale of it. In a way that's not just writing down the scale of this swatch.	P3-2
the side of the fabric simulated not well in fabric test videos		I agree with that too. And something like for some reason with it looking kind of like a twill weave from the side. Also, was it off for me like when it turns you can like see that it's actually not but I don't know from like the side view. Especially with the stretching one It only looks like it's kind of got those, like diagonal stripes on it. Just looks like weird	P5-2
	use virtual fabric with printed patterns to magnify the texture feature when fabric being distorted Use vitrual hand has an indicator of scale	Many fabric were offered in this website called fabric wholesale direct. And they have their like swatch like videos, but it's like a guy like pulling it with his hands. And I think I've just been thinking about this ever since we talked about scale that that's nice because it automatically gives scale for like the average person says 10s you know so maybe if it was like instead of the two bars maybe if it was like like virtual like hands or something maybe that would be nice. And I think I know like as from a textile perspective Gray's the best thing to be able to like like dark like be able to like judge depth. But I think for the average consumer, maybe making like the garments a solid color and then the like swatch a print or something like that might help	P7-2
The dancing movement can show human body motions comprehensively.		I thought the dance thing that she was doing was such a creative way to show different motions a lot of like, if I ever see anything like usually it's like a video and rather than like an digitally simulated thing, but it's always with active wear like running or like the weight like this. And the motions I think that that the Avatar was doing I think it it showcases a lot of ways that your body moves while	P3-2

Codes of comments	Codes of suggestions	Quotes	Speaker
		you’re exercising that aren’t shown as much. That is very interesting. It shows kind of all your different muscle groups being used.	

Appendix F: Full MaxDiff conjoint survey used in Phase 2

Activewear question

Thank you for your interest in participating. Could you please confirm if you shop for, browse, or use women's activewear?

- ○ Yes, I shop for, browse, or use women's activewear.
- ○ No, I don't shop for, browse or use women's activewear.

Consent Forms

Which academic year are you currently in?

- ○ Freshman/First Year
- ○ Sophomore/Second Year
- ○ Junior/Third Year
- ○ Senior/Fourth Year
- ○ Graduate Student
- ○ Other (please specify) ______

What is your primary major or field of study?

- ○ Fashion and Textile Design
- ○ Fashion and Textile Management
- ○ Polymer and Color Chemistry
- ○ Textile Engineering
- ○ Textile Technology
- ○ Fiber and Polymer Science
- ○ Textile Technology Management
- ○ Others (please specify) ______

Thank you for providing the information! You're invited to participate in a survey examining the visual perception of clothing movement in 3D apparel simulations. The goal is to better understand how individuals interpret clothing motion in these virtual environments.
To be eligible, you must be a current Wilson College of Textile Student at least 18 years of age and currently reside in the United States. Your involvement is entirely voluntary. Should you choose, you can exit the survey at any time.
If you have questions about the study, please contact the student researcher, Ziwen Qiu, at zqiu3@ncsu.edu and 919-348-3405. You can also contact the faculty advisor for this research, Anne Porterfield, at japorter@ncsu.edu and 919-515-5181. Please reference study number #24577 when contacting anyone about this project.
If you have questions about your rights as a participant or are concerned with your treatment throughout the research process, please contact the NC State University IRB Director at IRB-Director@ncsu.edu, 919-515-8754, or fill out a confidential form online at https://research.ncsu.edu/administration/participant-concern-and-complaint-form/
To proceed, simply click on the "I consent, begin the study" button.

Consent Form

Title of Study: Exploring Clothing Movement in 3D Apparel Motion Simulation (eIRB # 24577)
Principal Investigator(s): Ziwen Qiu, zqiu3@ncsu.edu, 919-348-3405
Funding Source: None
NC State Faculty Point of Contact: Anne Porterfield, japorter@ncsu.edu, 919-515-5181
Collaborating Researchers: Anne Porterfield, japorter@ncsu.edu, 919-515-5181; Kavita Mathur, kmathur@ncsu.edu, 919-515-4742

What are some general things you should know about research studies?
You've been invited to participate in a research study focused on the perception of clothing movement in simulated 3D apparel. Participation is entirely voluntary, meaning you have the freedom to join, decline, or withdraw from the study at any point without any consequences. Our aim is to understand how individuals perceive and compare the visual and tactile sensations of virtual fabrics presented within the survey.
While participation does not guarantee personal benefits, there may be inherent risks associated with research studies. Your interest in 3D apparel simulation might motivate

you to participate. Conversely, if you're uncomfortable with recording your perceptions based on sight and touch, you might choose not to join.
Further specifics regarding the study are detailed below. If any aspect of this consent form is unclear, please reach out to the researcher for more information or clarification. You'll receive a copy of this form for your records, and you can contact the researcher(s) or the NC State IRB office anytime should you have questions about your involvement in the study. The IRB office's contact information is listed in the What if you have questions about your rights as a research participant? section of this form.

What is the purpose of this study?
The study investigates the perception of clothing movement within 3D simulations, with a specific emphasis on women's activewear in the U.S market. The objective is to determine how U.S consumers perceive the movement of women's activewear when presented in simulated 3D motion. The research aims to understand the relationship between virtual fabric parameters and the descriptors associated with clothing movement. Additionally, the study seeks to pinpoint which elements of these virtual fabric parameters most profoundly influence the viewer's perception of comfort.

How many people will be in the study?
There will be approximately 90-110 participants in this study.

Am I eligible to be a participant in this study?
In order to be a participant in this study, you must:

- Be a current Wilson College of Textile student over 18 years of age and currently reside in the United States
- Shop/browse/use women's activewear
- Agree to be in the study

You cannot participate in this study if you do not meet the inclusion criteria stated above.

What will happen if you take part in the study?
If you agree to participate in this study, you will be tasked with watching simulated videos and comparing them on your computer or mobile device. Your evaluations will be based on the descriptors provided within the survey questions to gauge your visual perception of clothing movement. The entire process is expected to take approximately 15 minutes of your time.

Risks and benefits
There are minimal risks associated with participation in this research.
There are no direct benefits to your participation in the research. The indirect benefit is to contribute to research in perceptions of 3D simulations of clothing so that apparel designers and developers can also take this into account in using this technology.

Right to withdraw your participation
You have the freedom to withdraw participation in this study at any point and for any reason. To discontinue, either stop the research activity you're engaged in or reach out to the student researcher, Ziwen Qiu, at zqiu3@ncsu.edu and 919-348-3405, or the faculty advisor, Anne Porterfield, at japorter@ncsu.edu and 919-515-5181. If you decide to withdraw your consent and cease participation, the researcher(s) will remove your data from their dataset and securely destroy it, ensuring it isn't used for future research. Please note that this is achievable in most, but not all, scenarios.

Confidentiality, personal privacy, and data management
Trust is the foundation of the participant/researcher relationship. Much of that principle of trust is tied to keeping your information private and in the manner that we have described to you in this form. The information that you share with us will be held in confidence to the fullest extent allowed by law.
Protecting your privacy as related to this research is of utmost importance to us. There are very rare circumstances related to confidentiality where we may have to share information about you. Your information collected in this research study could be reviewed by representatives of the University, research sponsors, or government agencies (for example, the FDA) for purposes such as quality control or safety. In other cases, we must report instances in which imminent harm could happen to you or others. How we manage, protect, and share your data are the principal ways that we protect your personal privacy. Data that will be shared with others about you will be anonymous.

Future use of your research data
To help maximize the benefits of your participation in this project, by further contributing to science and our community, your anonymous information will be stored for future research and may be shared with other people without additional consent from you.

Compensation

There is no compensation for participating in this study.

What if you are a student?
Your participation in this study is not a course requirement and your participation, or lack thereof, will not affect your class standing or grades.

What if you are an employee?
Your participation in this study is not a requirement of your employment, and your participation or lack thereof, will not affect your job.

What if you have questions about this study?
If you have questions at any time about the study itself or the procedures implemented in this study, you may contact the student researcher, Ziwen Qiu, at zqiu3@ncsu.edu and 919-348-3405. You can also contact the faculty advisor for this research, Anne Porterfield, at japorter@ncsu.edu and 919-515-5181.

What if you have questions about your rights as a research participant?
If you feel you have not been treated according to the descriptions in this form, or your rights as a participant in research have been violated during the course of this project, you may contact the NC State IRB (Institutional Review Board) office. An IRB office helps participants if they have any issues regarding research activities. You can contact the NC State University IRB office at IRB-Director@ncsu.edu, 919-515-8754, or fill out a confidential form online at https://research.ncsu.edu/administration/participant-concern-and-complaint-form/

Consent to participate
By signing this consent form electronically, I am affirming that I have read and understand the above information. All the questions that I had about this research have been answered. I have chosen to participate in this study with the understanding that I may stop participating at any time without penalty or loss of benefits to which I am otherwise entitled. I am aware that I may revoke my consent at any time.

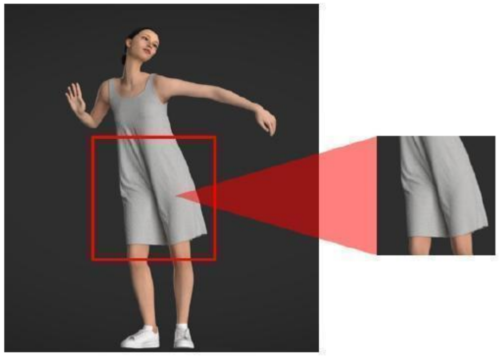
- ○ Yes, I want to participate in this research study
- ○ No, I do not want to be in this research study

Intro

Thank you for completing the consent forms. The formal survey will begin on the next page.

In this survey, you will be presented with 9 sets, each containing three videos. These videos display different 3D simulated clothing pieces in motion, taken from an animation where an avatar dances in a loose jumpsuit (as shown below). This design is specifically chosen to accentuate the movement of clothing around the avatar's abdomen, crotch, and leg openings.

For every video set, you will be asked to evaluate your visual perception using specific descriptors like "comfortable", "flexible", and more. Each set will be accompanied by three questions. You must answer all three questions to proceed to the next video set.



V1, V2, V3

Given the clothing simulation videos above, please select the video that shows the **fabric** you find to be the MOST **flexible** and the one you perceived to be the LEAST flexible.
Note: For the purposes of this survey, "flexible" refers to the fabric's ability to "move with the body".

MOST		LEAST
○	the 1st video	○
○	the 2nd video	○
○	the 3rd video	○

Given the clothing simulation videos above, please select the video that shows the **fabric** you find to be the MOST **supportive** and the one you perceived to be the LEAST supportive.
Note: For the purpose of this survey, "supportive" refers to to the fabric's tendency to gap and wrinkle: the more it gaps and wrinkles, the less supportive the fabric is considered.

MOST		LEAST
○	the 1st video	○
○	the 2nd video	○
○	the 3rd video	○

Given the clothing simulation videos above, please select the video that shows the **fabric** that seems the MOST **comfortable** and the one that seems LEAST comfortable.

MOST		LEAST
○	the 1st video	○
○	the 2nd video	○
○	the 3rd video	○

Rep - V1, V2, V3

Given the clothing simulation videos above, please select the video that shows the **fabric** you find to be the MOST **flexible** and the one you perceived to be the LEAST flexible.
Note: For the purposes of this survey, "flexible" refers to the fabric's ability to "move with the body".

MOST		LEAST
○	the 1st video	○
○	the 2nd video	○
○	the 3rd video	○

Given the clothing simulation videos above, please select the video that shows the **fabric** you find to be the MOST **supportive** and the one you perceived to be the LEAST supportive.
Note: For the purpose of this survey, "supportive" refers to to the fabric's tendency to gap and wrinkle: the more it gaps and wrinkles, the less supportive the fabric is considered.

MOST		LEAST
○	the 1st video	○
○	the 2nd video	○
○	the 3rd video	○

Given the clothing simulation videos above, please select the video that shows the **fabric** that seems the MOST **comfortable** and the one that seems LEAST comfortable.

MOST		LEAST
○	the 1st video	○
○	the 2nd video	○
○	the 3rd video	○

V4, V5, V6

Given the clothing simulation videos above, please select the video that shows the **fabric** you find to be the MOST **flexible** and the one you perceived to be the LEAST flexible.
Note: For the purposes of this survey, "flexible" refers to the fabric's ability to "move with the body".

MOST		LEAST
○	the 1st video	○
○	the 2nd video	○

MOST		LEAST
○	the 3rd video	○

Given the clothing simulation videos above, please select the **fabric** you find MOST **supportive** and the one you find LEAST supportive.
Note: For the purpose of this survey, "supportive" refers to to the fabric's tendency to gap and wrinkle: the more it gaps and wrinkles, the less supportive the fabric is considered.

MOST		LEAST
○	the 1st video	○
○	the 2nd video	○
○	the 3rd video	○

Given the clothing simulation videos above, please select the video that shows the **fabric** that seems the MOST **comfortable** and the one that seems LEAST comfortable.

MOST		LEAST
○	the 1st video	○
○	the 2nd video	○
○	the 3rd video	○

V7, V8, V1

Given the clothing simulation videos above, please select the video that shows the **fabric** you find to be the MOST **flexible** and the one you perceived to be the LEAST flexible.
Note: For the purposes of this survey, "flexible" refers to the fabric's ability to "move with the body".

MOST		LEAST
○	the 1st video	○
○	the 2nd video	○
○	the 3rd video	○

Given the clothing simulation videos above, please select the video that shows the **fabric** you find MOST **supportive** and the one you perceived to be the LEAST supportive.
Note: For the purpose of this survey, "supportive" refers to to the fabric's tendency to gap and wrinkle: the more it gaps and wrinkles, the less supportive the fabric is considered.

MOST		LEAST
○	the 1st video	○
○	the 2nd video	○
○	the 3rd video	○

Given the clothing simulation videos above, please select the video that shows the **fabric** that seems the MOST **comfortable** and the one that seems LEAST comfortable.

MOST		LEAST
○	the 1st video	○
○	the 2nd video	○
○	the 3rd video	○

V2, V3, V4

Given the clothing simulation videos above, please select the video that shows the **fabric** you find to be the MOST **flexible** and the one you perceived to be the LEAST flexible.
Note: For the purposes of this survey, "flexible" refers to the fabric's ability to "move with the body".

MOST		LEAST
○	the 1st video	○
○	the 2nd video	○
○	the 3rd video	○

Given the clothing simulation videos above, please select the video that shows the **fabric** you find to be the MOST **supportive** and the one you perceived to be the LEAST supportive.
Note: For the purpose of this survey, "supportive" refers to to the fabric's tendency to gap and wrinkle: the more it gaps and wrinkles, the less supportive the fabric is considered.

MOST		LEAST
○	the 1st video	○
○	the 2nd video	○
○	the 3rd video	○

Given the clothing simulation videos above, please select the video that shows the **fabric** that seems the MOST **comfortable** and the one that seems LEAST comfortable.

MOST		LEAST
○	the 1st video	○
○	the 2nd video	○
○	the 3rd video	○

V5, V7, V8

Given the clothing simulation videos above, please select the video that shows the **fabric** you find to be the MOST **flexible** and the one you perceived to be the LEAST flexible.
Note: For the purposes of this survey, "flexible" refers to the fabric's ability to "move with the body".

MOST		LEAST
○	the 1st video	○
○	the 2nd video	○
○	the 3rd video	○

Given the clothing simulation videos above, please select the video that shows the **fabric** you find MOST **supportive** and the one you find LEAST supportive.
Note: For the purpose of this survey, "supportive" refers to to the fabric's tendency to gap and wrinkle: the more it gaps and wrinkles, the less supportive the fabric is considered.

MOST		LEAST
○	the 1st video	○
○	the 2nd video	○
○	the 3rd video	○

Given the clothing simulation videos above, please select the video that shows the **fabric** that seems the MOST **comfortable** and the one that seems LEAST comfortable.

MOST		LEAST
○	the 1st video	○
○	the 2nd video	○
○	the 3rd video	○

V1, V6, V7

Given the clothing simulation videos above, please select the video that shows the **fabric** you find to be the MOST **flexible** and the one you perceived to be the LEAST flexible.
Note: For the purposes of this survey, "flexible" refers to the fabric's ability to "move with the body".

MOST		LEAST
○	the 1st video	○
○	the 2nd video	○

MOST		LEAST
○	the 3rd video	○

Given the clothing simulation videos above, please select the video that shows the **fabric** you find MOST **supportive** and the one you find LEAST supportive.
Note: For the purpose of this survey, "supportive" refers to to the fabric's tendency to gap and wrinkle: the more it gaps and wrinkles, the less supportive the fabric is considered.

MOST		LEAST
○	the 1st video	○
○	the 2nd video	○
○	the 3rd video	○

Given the clothing simulation videos above, please select the video that shows the **fabric** that seems the MOST **comfortable** and the one that seems LEAST comfortable.

MOST		LEAST
○	the 1st video	○
○	the 2nd video	○
○	the 3rd video	○

V3, V5, V4

Given the clothing simulation videos above, please select the video that shows the **fabric** you find to be the MOST **flexible** and the one you perceived to be the LEAST flexible.
Note: For the purposes of this survey, "flexible" refers to the fabric's ability to "move with the body".

MOST		LEAST
○	the 1st video	○
○	the 2nd video	○
○	the 3rd video	○

Given the clothing simulation videos above, please select the video that shows the **fabric** you find MOST **supportive** and the one you find LEAST supportive.
Note: For the purpose of this survey, "supportive" refers to to the fabric's tendency to gap and wrinkle: the more it gaps and wrinkles, the less supportive the fabric is considered.

MOST		LEAST
○	the 1st video	○
○	the 2nd video	○
○	the 3rd video	○

Given the clothing simulation videos above, please select the video that shows the **fabric** that seems the MOST **comfortable** and the one that seems LEAST comfortable.

MOST		LEAST
○	the 1st video	○
○	the 2nd video	○
○	the 3rd video	○

V2, V8, V7

Given the clothing simulation videos above, please select the video that shows the **fabric** you find to be the MOST **flexible** and the one you perceived to be the LEAST flexible.
Note: For the purposes of this survey, "flexible" refers to the fabric's ability to "move with the body".

MOST		LEAST
○	the 1st video	○
○	the 2nd video	○
○	the 3rd video	○

Given the clothing simulation videos above, please select the video that shows the **fabric** you find MOST **supportive** and the one you find LEAST supportive.
Note: For the purpose of this survey, "supportive" refers to to the fabric's tendency to gap and wrinkle: the more it gaps and wrinkles, the less supportive the fabric is considered.

MOST		LEAST
○	the 1st video	○
○	the 2nd video	○
○	the 3rd video	○

Given the clothing simulation videos above, please select the video that shows the **fabric** that seems the MOST **comfortable** and the one that seems LEAST comfortable.

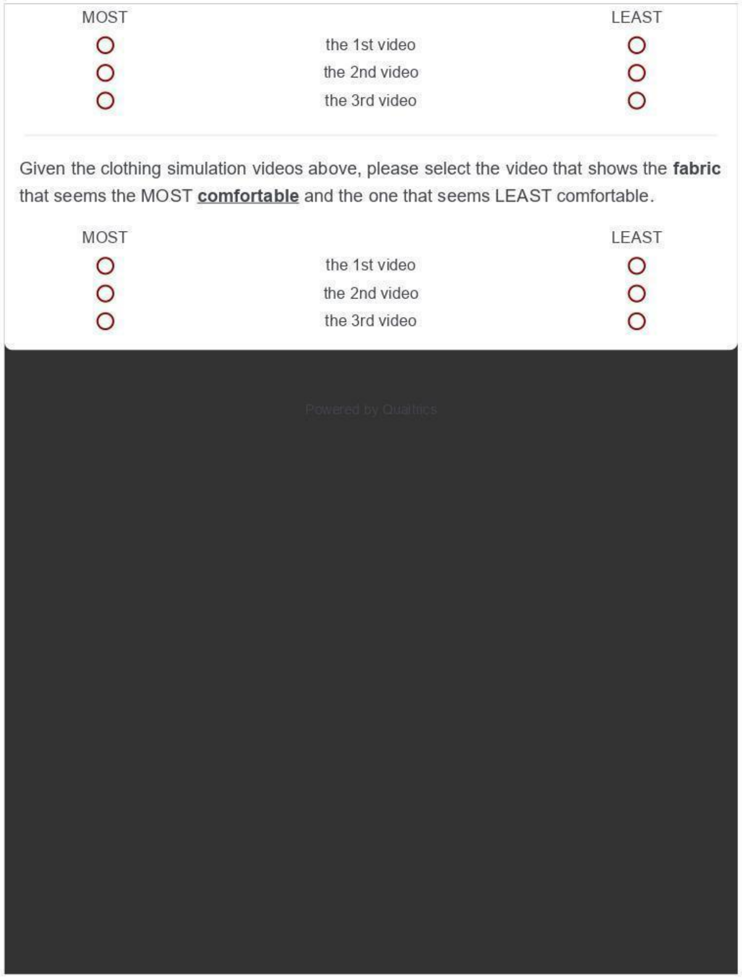
MOST		LEAST
○	the 1st video	○
○	the 2nd video	○
○	the 3rd video	○

V6, V1, V3

Given the clothing simulation videos above, please select the video that shows the **fabric** you find to be the MOST **flexible** and the one you perceived to be the LEAST flexible.
Note: For the purposes of this survey, "flexible" refers to the fabric's ability to "move with the body".

MOST		LEAST
○	the 1st video	○
○	the 2nd video	○
○	the 3rd video	○

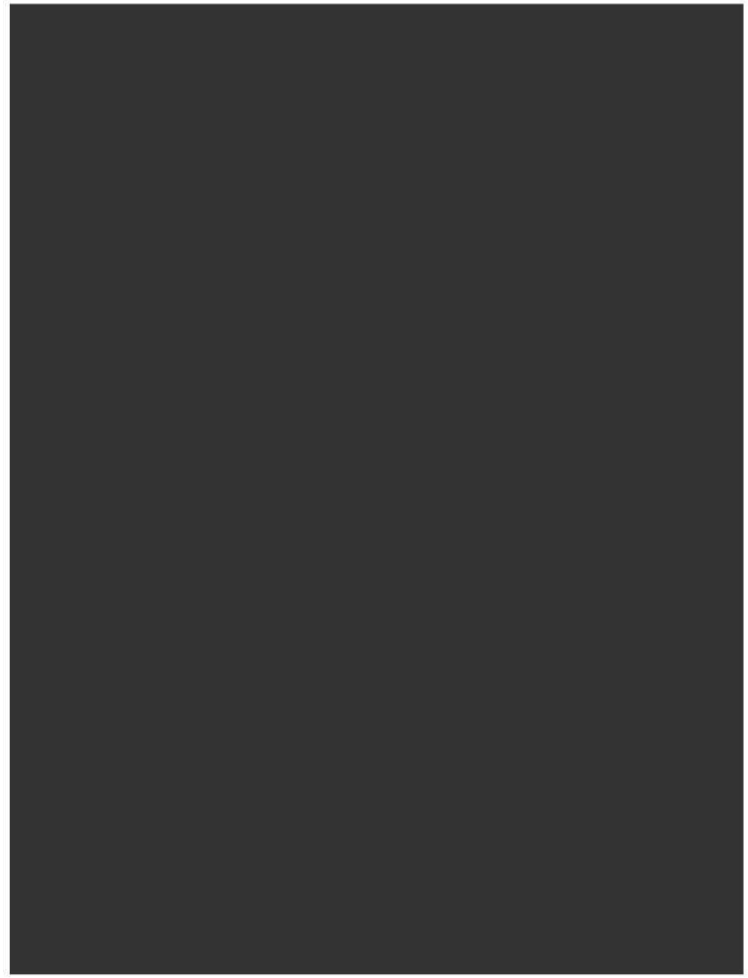
Given the clothing simulation videos above, please select the video that shows the **fabric** you find MOST **supportive** and the one you find LEAST supportive.
Note: For the purpose of this survey, "supportive" refers to to the fabric's tendency to gap and wrinkle: the more it gaps and wrinkles, the less supportive the fabric is considered.


MOST		LEAST
○	the 1st video	○
○	the 2nd video	○
○	the 3rd video	○

Given the clothing simulation videos above, please select the video that shows the **fabric** that seems the MOST **comfortable** and the one that seems LEAST comfortable.

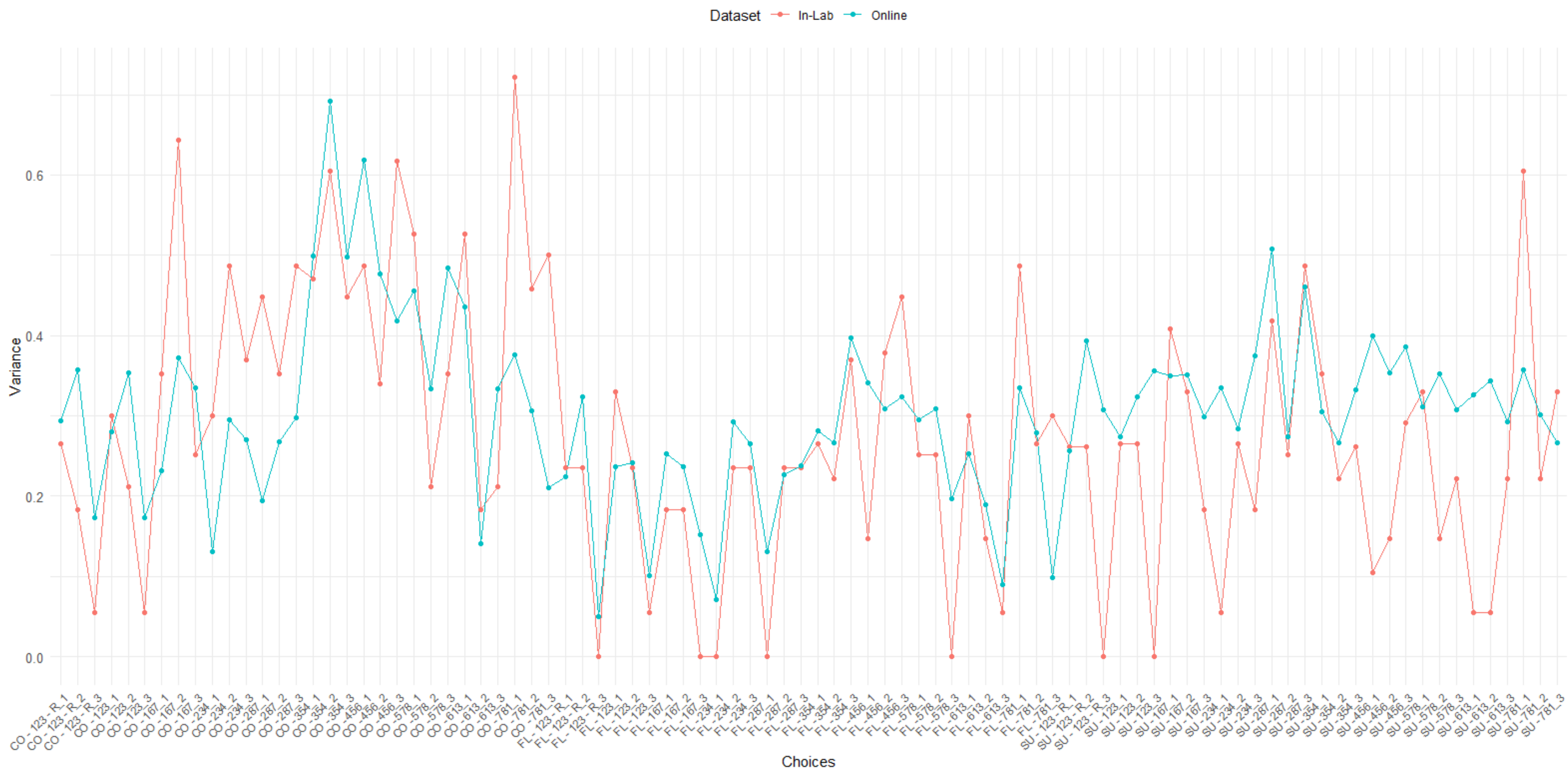
MOST		LEAST
○	the 1st video	○
○	the 2nd video	○
○	the 3rd video	○

Powered by Qualtrics



Note. This appendix provides an overview of all the questions and visual elements included in the survey. The IDs assigned to each question in this preview are not visible to participants. The sequence of the questions here does not reflect the actual order in which participants have encountered them in the live questionnaire.

Appendix G: Interobserver variability comparison of all 30 survey questions



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