Exploring Visual Perception of Clothing Movement in 3D Activewear Motion Simulation: A Focus Group Study

Ziwen Qiu, Anne Porterfield, and Kavita Mathur North Carolina State University, USA

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Background: Advancements in 3D Computer-Aided Design (CAD) systems have significantly transformed apparel display, enabling the simulation of garment movement with remarkable realism (Gonzalez, 2022; Dal Forno et al., 2023). These systems aim to replicate the dynamics of clothing in motion, potentially enhancing digital interactions between consumers and fabric. However, there exists a notable gap in understanding how these fabric motion simulations effectively convey clothing movement to viewers (Sun & Zhao, 2018). Specifically, the impact of adjusting digital replicas' virtual properties on viewer perceptions has been insufficiently explored. To address this research gap, this study investigates the visual-tactile perceptions elicited by 3D apparel motion simulations to improve how clothing movement is presented to potential audiences.

Method: All 3D apparel simulations and animated videos for this study were created using CLO software (Versions 7.1 and 7.3). CLO was selected over other popular 3D apparel CAD programs due to its superior adaptability to external files and reliable animation capabilities. Fashion and textile students were chosen as participants due to their familiarity with clothing and textiles through academic coursework, which enriched the quality of discussion data with their detailed descriptions of fabric and apparel. Their interest in online shopping and innovative apparel displays aligned well with the study's objectives (Jeong et al., 2009). A pilot focus group study was conducted first to evaluate the feasibility of the purposive sampling method and qualitative exploration approach. In the pilot study, four participants joined a one-hour Zoom session, viewing six videos featuring virtual apparel simulations with a broad range of fabrics, colors, and avatar movements (see Figure 1). The primary study included two online focus groups with 15 student participants in total. They were shown six sets of videos showcasing three CLO virtual fabric properties (stretch & shear, bending, and density) with contrasting values to examine their influence on perceptions of clothing movement (Luible & Magnenat-Thalmann, 2007; Kuijpers et al., 2020; Ju & Choi, 2020; CLO, 2023). These videos, demonstrating the virtual fabric capabilities (Figure 2) and featuring a female avatar in activewear (Figure 3), facilitated rich discussions. At the start of each focus group, participants answered two general questions about their experiences with evaluating activewear online and their familiarity with 3D simulations in online shopping. Afterward, they were shown the simulation videos in a predetermined order. Participants could request replays to better assess the visuals. The discussion ended with how the simulation influenced their perceptions of apparel mobility and comfort. The interview transcripts were analyzed using thematic analysis.

Pilot Study Results: In the pilot study, connections were found between the fabric performance estimation and the visual features highlighted. Participants commented, "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", indicating that fabric texture may influence the perception of breathability. The discussion also suggested that clear fabric texture increased participants' visual impression of fabric stretchability. One 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." The looseness of the garment also made participants perceive the fabric as soft, supported by the comments, "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." The pilot study suggested that the visual impression of the simulation potentially influenced clothing movement perception, indicating the feasibility of the qualitative exploration approach. The pilot study also revealed that the textured surface of the light gray fabric in the jumpsuit simulation, contrasted with the background, most effectively highlighted movement details. Participants preferred seeing the avatar in the video and often used generalized terms like "comfortable" and "fit" rather than describing garment mechanics. These insights shaped the simulation design and prompted the use of targeted questions in the primary study to elicit detailed feedback.

Primary Study Results: The focus group discussions were segmented into three primary content areas: (1) Mobility, Functionality, and Comfort Evaluation in Online Shopping; (2) Description of Visual and Tactile Sensations of Viewing Virtual Fabric; and (3) Comments on Simulation and Display, where Content Area 2 was of particular interest. The analysis identified five key themes as critical dimensions of visual comfort: flexibility, drapability, supportability, weight, and thickness. *Flexibility* is a dominant theme consistently emphasized by participants. Two movements highlighted *high flexibility*: *Bouncing* was observed mostly during fabric pulling simulations, indicated the fabric's ability to spring back ("the bounce back seemed like very strong and easy to recover", "it seems like it snaps back pretty easy", and "it pulls a lot more and it kind of like bounces"). *Moving with the body* was seen in avatar simulations. Participants described how fabrics stretched and adjusted to body contours ("if you move left, the fabric will move left, but then kind of go back to being like straight" (describing the leg opening of the jumpsuit), and "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"). In contrast, *low flexibility* was described as static, with fabric and body moving independently ("It didn't really bounce back or anything. It kind of just held its own shape", and "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."). *Drapability* and *supportability* described how the fabric maintained shape and flow. *High drapability* fabrics were described as flowy and bouncing, indicating smooth contours and fluid movement ("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", and "It feels like it, it bounces back more, I think it might be like, in my brain ... it's still fairly drapey."), while *low drapability* fabrics were described as not flowing ("...it's not made to be loose and flowy"). *Supportability* described how fabrics handled compression and stiffness. Participants described *high-support* fabrics static, creating minimal creases ("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...", and "It doesn't really. Like there's no draglines or like, you know."), while *low-support* fabrics wrinkled or gapped ("…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", and "It kind of looks like in the back there, there might be like some, like gapping between her back and the fabric."). *Weight* was primarily discussed on fabric pulling and loose activewear simulations.

Participants rarely commented on lightweight properties, suggesting these visual cues might not be as noticeable in virtual settings. Heavier fabrics were associated with weighted recovery and draping in the pulling simulations ("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"). *Thickness* was inferred indirectly through other themes, such as the visual cues of wrinkling, flowing, and bouncing that are associated with *drapability* and *supportability*. Participants described these thin fabrics as having low supportability and high drapability, while thickness itself received limited direct commentary.
In summary, the similarity of the visual cues among *flexibility*, *supportability*, and *drapability* suggest that these three dimensions are the core visual comfort dimensions, and they might inherently include the concept of *thinness* when they convey fabric movement visually. *Drapability* hinted at functionality, adding another layer to visual comfort assessments. In addition, how fabrics bounce in the pulling simulation videos seems to inform perceptions of weight—stronger bounces imply heaviness, while lighter bounces suggest lightness. This implied that the visual cues could contrast with the actual density settings for fabrics, influenced by the overall visual impression created by *flexibility* and *supportability* cues.
Conclusions: Descriptors of clothing movement for loose activewear and fabric pulling simulations were identified, as shown in Figure 4a and 4b. The next research phases should incorporate the descriptors with close-up simulation videos to conduct quantitative analysis with a larger sample.

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Figure 1
Simulations Used in the Pilot Study

Figure 2
Virtual Fabric Motion Simulations: Pulling, Sliding, and Twisting

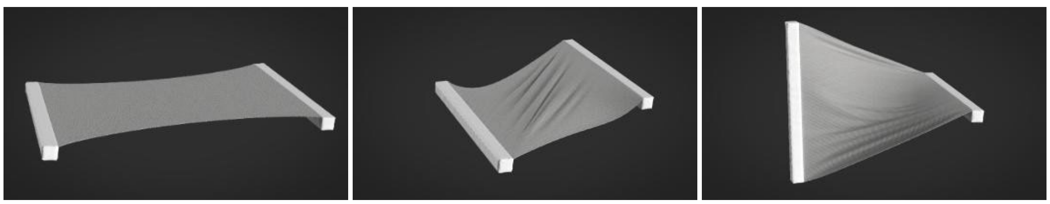


Figure 3
Apparel Motion Simulations: Loose and Tight Jumpsuit

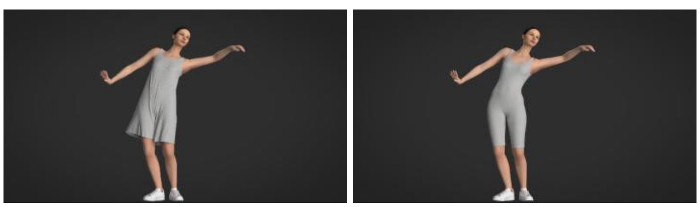
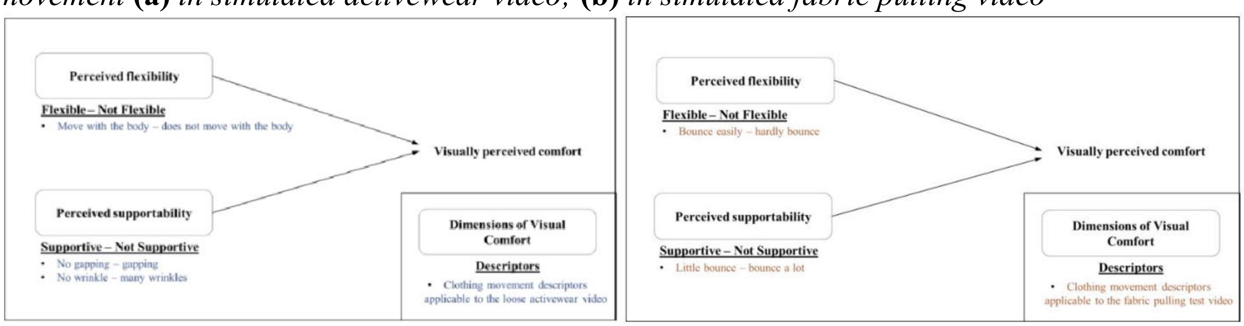


Figure 4
Proposed dimensions of visual comfort and their corresponding descriptors of clothing movement **(a)** *in simulated activewear video;* **(b)** *in simulated fabric pulling video*



(a) **(b)**