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Fit models' roles in identifying fit issues in the apparel technical design process and implications for improving 3D virtual fitting

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Abstract

Fit sessions are essential in making well-fitted clothing. During these sessions, apparel fit is determined iteratively by a team of designers, technical designers, fit models, and merchandisers. With the advent of the digitalization of new product development processes in the fashion industry, fit sessions have been seen as a bottleneck for they are still held in person. However, the process is currently still irreplaceable, and what makes the feedback provided by fit models important is an area that has never been tapped. Therefore, the present study aimed to understand fit models' role in fit sessions as well as how they assess the fit of garments and deliver their feedback. On-site observation during fit sessions and individual interviews with fit models were conducted. It was found that fit models gave comfort, fit, and tactile comments by testing garments while standing and moving between several postures. They had knowledge that overlapped with those of technical designers and designers and this empowerment enabled them to take part in the decision-making process in fit sessions. It also was found that fit models' feedback on garments was essential as they were the first people to try on the garments and present the customers' points of view.

Keywords: Fit session, Fit model, New product development, 3D virtual fitting, Avatars

Introduction

Digital technologies such as computer-aided design (CAD) patternmaking, virtual prototyping, and testing garment fit on 3D avatars have been acceleratingly adopted by apparel companies (Mesjar et al., 2023). The impact of COVID-19 has been compelling brands to actively embrace and explore immersive technologies (Roberts-Islam, 2020), but there is still much room for the transformation of apparel product development toward digitalization. Well-fitted garments guarantee higher sales in the market and higher customer satisfaction (Gill, 2011). To achieve that, apparel fit is perfected by a team of designers, technical designers, fit models, and merchandisers during the development process before sending patterns for mass production.

Even if an apparel fit session team can potentially conduct fit assessments remotely, there are certain elements related to analog garment-human interactions that are currently difficult to replace. In a digital environment, avatars are the digital counterparts of human fit models. They can be parametric or body scans of the company's fit models. One way to understand avatar body-digital garment interaction would be by analyzing the tension maps and stress and strain maps, however, these tools still need to be improved. To advance the existing technology offerings and tools, it is necessary to understand analog settings first. Therefore, there is a need to investigate fit models' strategic roles in providing fit feedback to the fit session team (Bougourd, 2007; Lee & Steen, 2014).) Fit models have a crucial role in determining the success of designs (Ilyashov, 2018). They represent the target customers of apparel brands and typically try on eight to 20 garments per fit session evaluating garment fit and details. They assist the technical design team in approving or rejecting initial designs, leading to fewer fit-related returns in retail once the garments are launched (Campbell et al., 2021; Clothierdesignsource, 2020).

Despite their importance in the new apparel product development, fit models' role has not been fully examined in the literature. One of the reasons could be that information discussed at fit sessions is considered company secret and non-disclosure agreement (NDA) procedures can limit what can be published and shared publicly. Nonetheless, for a true digital transformation, there is a need to analyze fit sessions. In this study, we focused on fit models and how they analyze and communicate fit feedback to the rest of the fit session team. An onsite observation and individual interviews were carried out to understand fit models' roles as well as their intentions and understandings behind their performance. Our study highlighted the importance of understanding the role of fit models in fitting sessions and their feedback mechanisms to improve 3D technologies in the apparel industry. The findings of this study can be used in workforce training, help reduce trial and error in fit testing, and enhance the effectiveness of 3D virtual fit testing in supporting the process of new product development. Study findings could also be beneficial to propel the development of 3D technologies as they currently focus on duplicating real-world features in 3D virtual environments (Zheng et al., 2023) and do not include the workflow in the industry.

Literature Review

Apparel technical design as a new product development process

The new product development process in apparel involves seven stages: idea discovery, idea screening, concept development, profitability analysis, product development, market testing, and commercialization (Kim et al., 2016). Each stage is performed by different team members who are designers, research managers, sales managers, or production managers. Before the market test stage, confirmed design sketches go through the technical design process where technical design teams develop prototypes and conduct product tests, which is referred to as fit testing or fit session (Choi, 2022; Kim et al., 2016). Once the prototype sample is ready, designers who developed fashion sketches, technical designers who oversee 2D patternmaking to realize the design ideas, and fit models who are the representative of customer baseline meet for fit sessions. The first prototype sample garment is altered in the first fit session and becomes the second sample to be tested in the next fit session. The alteration and making of samples continue until the garment meets the company's fit standard.

Fit

During fit assessment sessions, the focus lies on evaluating five key elements of garment fit that are ease, balance, set, grain, and line (Erwin & Kinchen, 1979; Kincade, 2008). Ease refers to the measurable difference between the size of the garment and the size of the person wearing it, representing the amount of space the wearer has beyond their body measurements (Erwin & Kinchen, 1979). Fit ease is essential to allow the garment to function well, enabling the wearer to move comfortably while wearing it. Additionally, design ease is added to achieve a specific silhouette and showcase the intended design of the garment (Lee & Steen, 2014).

Grain is determined by its relationship with the fabric's grainline and the structural style lines of the garment (Lee & Steen, 2014). The vertical grainline of the garment must be parallel to the length of the wearer's torso at the front and back, along with the center of their arms between shoulders and elbows, and the center through their legs. Similarly, the vertical grainline of the garment should be perpendicular to the wearer's bust and hip levels (Lee & Steen, 2014). Line indicates that design lines and seam lines should follow the body contour and curves (Sayem, 2023). A well-fitted garment aligns its landmark points, such as the center front waist point, with the corresponding body landmark points and ensures the garment's landmark lines align with the body's landmark lines. Set refers to how smoothly the garment sits on the wearer's body without any unintended wrinkles or fabric tensions (Lee & Steen, 2014). Wrinkles indicate potential issues with the fit. Two main categories of wrinkles, namely tight and loose, come in three different forms: horizontal, vertical, and diagonal. The existence of any of these wrinkle types can signal various issues with the fit of clothing, such as inadequate, excessive, or misplaced ease (Brown & Rice, 2014; Liechty et al., 2010). Balance refers to the symmetry of the garment unless it is designed to be asymmetrical.

Fit issues arise when one or more of these five elements of fit are not met. In such cases, adjustments must be made to the garment's 2D patterns to correct the fit of the 3D garment. Technical designers and designers detect the fit issues by identifying visual cues (i.e., set). The more experienced they are, the better they become at identifying causes and solutions to the issues. Additionally, fit models play a crucial role as they can provide feedback on the garment's fit and comfort, identifying areas that may be too tight or loose and offering comments on their tactile experience, in both static and motion situations (Sayem, 2023).

Fit models

Fit session teams prefer working with human fit models instead of using dress forms because they can receive verbal comments on tactile and comfort experiences (Bougourd, 2007; Lee & Steen, 2014). Fit models represent target customers of clothing brands and have preferred measurement specifications that designers or manufacturers want (Clothierdesignsource, 2020; Omotoso, 2018). Unlike tall and slim runway models, who represent only a small fraction of bodies, fit models are recruited to test garments manufactured to be sold in retail targeting a wide range of customers (Petite Poire, 2017). Although fit models cannot represent every single customer, they should share similar anthropometric features and age ranges with the target customers (Omotoso, 2018). Their sizes are usually the middle size of the customer sizes range (Sample Room, 2015).

They are also expected to maintain proper postures and body measurements during the multiple fit sessions (Ilyashov, 2018).

Fit models should be experienced enough to give quality comments in fit sessions and point out fit issues to make sure the company gets useful feedback from the wearer's perspective (Model Scouts, n.d.; Peach Fitting Models, n.d.). They usually test eight to 20 garments per visit. Because evaluating every garment in detail takes too long to complete in one fit session, fit sessions are held repetitively to make sure the fit issues related to each garment are resolved in the consequent meetings (Campbell et al., 2021). Over ninety percent of garments in fit sessions are evaluated on fit models two to three times during the product development process (Bye & LaBat, 2005).

Precise and detailed feedback plays a vital role in achieving a garment fit. It offers comfort to the wearer, and ultimately boosts the wearer's confidence. When fit models evaluate garments, they go through the fitting process as customers would and comment on whether it is easy to put on or if the pockets are useful. They also walk and move their bodies to see if the garment feels comfortable. They also are professionals in garment development as they comment on how each design element functions and bring their knowledge such as how specific ease amount affects a certain part of the garment (Lee & Steen, 2014). This level of input allows the fit session teams to evaluate whether any design element should be altered or adjusted to achieve the desired outcome. As a result, it can be inferred that fit models are also a part of problem-solving as well as decision-making and therefore are essential figures in the process.

3D virtual fitting

Once 2D pattern pieces are ready, they can be virtually sewn and draped on avatars after placing pattern pieces close to the corresponding body parts of avatars. Simulating garments in 3D supports idea screening and the concept development stages as many iterations can be developed and tested without needing to spend resources to make physical sample garments (Chaudhary et al., 2020; Špelic, 2020). In the product development stage which includes fit sessions, it is still debated whether CAD technologies are reliable when making final decisions regarding the fit and sizing of garments (Hwang & Lee, 2020; Kim et al., 2019). When the garments are simulated in a 3D CAD software program such as CLO3D, Optitex PDS, or Browzwear V-Stitcher, the virtual fitting may not give information on how snug the garment is. This is because digital avatars cannot replicate the soft tissue of human bodies effectively. A few 3D CAD software programs including V-Stitcher and CLO3D added new functions that enabled users to try virtual fitting on soft avatars (Ailabouni, 2023; Clo3d, 2023). Yet the degree of deformation of avatars is descriptive i.e., soft, medium soft, or firm (Ailabouni, 2023) and the reliability of virtual fitting results has not been verified. Even though some existing studies reported promising results (Harrison et al., 2018; Meshcapade, 2024), replicating the compressibility and the elastic limit of human skin, which is the key component to scoring the fit and comfort of garments, requires further work (Balach et al., 2021; McDonald et al., 2023).

Almost all 3D CAD software programs include pressure maps to show the tightness of garments when worn on an avatar, however, they do not provide conclusive clues to identify fit issues especially when the pressure distribution of garments changes in dynamic poses (Brubacher et al., 2023; Teyeme, 2023). Moreover, depending on their past experiences and personal preferences, wearers may experience different levels of discomfort depending on where the pressure has been exerted (Ashdown & DeLong, 1995; Park et al., 2019). Digital avatars currently cannot replicate the complex process of fit analysis. A fundamental understanding of fit models' roles in fit sessions and their feedback mechanism is needed to improve the 3D technologies in the apparel industry. Considering this increasing need, the following research questions (RQs) were formulated to investigate how fit models give feedback and perform in fit sessions:

RQ1: What type of feedback do fit models provide?

RQ2: What is the process through which fit models identify fit issues and propose solutions?

Methods

The present study used qualitative research methods in two phases under the approval and supervision of the Cornell Institutional Review Board for Human Participants (IRB Approval No: 210801049) regarding ethical issues, including consent to participate. In the first phase, phase 1, physical fit sessions where the designers and fit models were conducting fit analysis and making comments on adjusting patterns, were observed. In the second phase, phase 2, individual interviews were carried out with fit models for aggregate analysis following the methods suggested by Denzin (1978). Recruiting fit models as interview participants was challenging as some of them were under NDAs with the apparel companies they were working with.

Participants

Participants in the first phase were fit models, technical designers, and designers who were older than 18 years and could communicate in English effectively (Table 1). The fit models had at least two years of experience at the time that the study was conducted. Because they were knowledgeable of the fit goals of the company and efficiently communicated with the team over time, they were deemed to possess rich data.

For the second phase, additional fit models were recruited by snowball sampling by contacting previous interview participants (Patton, 1987). Purposeful sampling was used to collect rich data from participants (Patton, 2002). The work experience of participants was considered to collect diverse interpretations from them. Although one of

Table 1 Phase 1 (fit session observation) participants

Pseudonyms	Sex	Occupation	Years of industry experience
Kai	M	Designer	25 + years
Ivy	F	Designer	2 years
Jayden	M	Designer	15 + years
Nova	F	Technical designer	15 + years
Mia	F	Fit model	5 years
Liam	M	Fit model	2 years

the part-time fit models had two years of experience, she was a plus-sized model who was mainly fitting intimates. As a result, she brought a different perspective and type of experience.

Data collection

Fit session observations took place in the Fall of 2022 at a small-scale US-based apparel company on the East Coast that produced men's and women's business attire. They were second-round fit sessions. The team had already held the first fit session to commence the discussion, was familiar with the styles, and gone over the initial iterations at the time of the observation. Seven tops and six bottoms including jackets, shirts, shorts, slacks, and joggers from the company's Spring 2023 and Fall 2023 collections were examined in the four-hour fitting session. On the fit session observation day, voice recorders were used to capture the conversations. The purpose of the study was explained to the fit session team before collecting data and consent forms were signed. During the observations, field notes were taken to document how fit models moved or posed, while fit models assessed fit issues. Immediately after the fit session, the voice recordings were uploaded to Otter.ai for transcribing.

Semi-structured fit model interviews in phase 2 were conducted via Zoom calls to capture how fit models assess fit. Participant consent forms were explained and signed before the interview sessions. Interviews were voice recorded and notes were taken during the discussions. The interview questions included previous work experience, how they describe their job as a fit model, and how they were trained to perform the job. Follow-up open-ended questions were asked to elaborate on their previous fit sessions to understand the context. Zoom meetings were recorded, and the voice files were uploaded to Otter.ai for transcribing.

Data analysis

The transcripts from both phases were coded in Microsoft Excel and analyzed through first and second-cycle coding (Saldaña, 2016). In vivo coding was used for the first cycle coding which was later followed by descriptive coding because in vivo codes contained participants' movements and needed to be translated into descriptive codes. The codes found in the first cycle of in vivo coding were cross-checked with the field notes. Physical movements of assessing fit issues were identified. On top of the physical motions, initial comments that fit models made in the fit session were reviewed. Codes from both data collections were integrated through pattern coding in the second cycle coding (Fig. 1).

As a result of pattern coding, themes were organized into main categories and subcategories, building the hierarchical tree of themes for detailed data analysis. For example, the code 'fabric', which later became a theme after pattern coding, was derived from the fit model's words such as "this is for summer". The fit model was touching the fabric after recognizing one of the garments, which had the same construction/design as a garment from the previous season but was made with summery seersucker fabric. Codes such as 'temporary', which later became a theme after pattern coding, derived from fit models' quotes such as "feeling a little full today". The findings were summarized and shared with the fit session attendees for their further comments and to achieve the trustworthiness of the results.

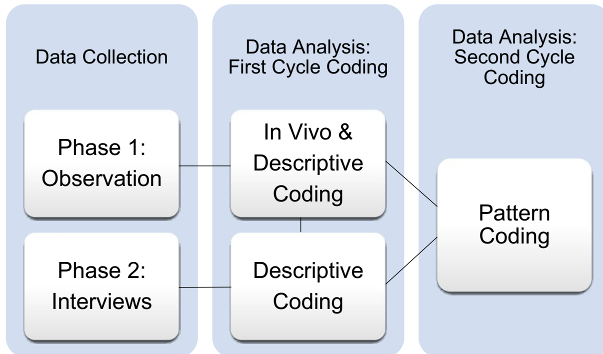

Fig. 1 The first and second cycles of coding to process the observation and individual interviews

Results and Discussion

Participants

In phase 1, two male designers, one female designer, one female technical designer, and two fit models (one man and one woman) participated in the fit session that was conducted at the business wear company. Both models fitted a range of woven garments that were cut and sewn. Additionally, they fitted shirts, jackets, short pants, and long pants from womenswear and menswear accordingly.

In addition, five fit models, four women, and one man were recruited for individual interviews in phase 2 (Table 2). Four of the models were size medium whereas one of them was a plus-size model. Moreover, four of the fit models had more than 14 years of professional experience while one of them (i.e., the plus-size fit model) was in the industry for less than three years. The clothing brands that they were working for spanned from athletic sports apparel to lingerie, and from luxury dresses to formal business wear (Table 2). None of the seven fit models had fashion-related education before they started working as fit models. Only one of them received a brief informal overview of the job professions from formal fit models. Most of the technical terms that they understood and used during their work were gained from their work experiences. Four fit models out of seven were full-time fit models, who did not have other occupations. The full-time fit models had clients of 25 apparel brands on average that they fit most womenswear or menswear ranging from business attire to casual attire. They also participated in fitting personal protective equipment (PPE) and scrubs during the COVID-19 crisis. The other three fit models were part-time fit models who had additional occupations with rather flexible schedules such as actors/actresses or estheticians.

Feedback types provided by fit models (RQ1)

Pattern coding revealed two main categories, which were labeled based on the feedback types of the fit models. The first category was 'Fit comments' (Category 1), which had two subcategories, i.e., 'Tactile' and 'Comfort', under which themes such as 'Fabric', 'Stitch', 'Trim', 'Placement', and 'Movement' were identified (Fig. 2a).

In subcategory 1, tactile refers to fit models' comments related to tactile experience, for example, "tension is too tight on the stitches and rolling in" (Olivia). They commented on how each fabric, trim, or stitch felt on their bodies. For example, "fabric too itchy" (Luna) and "tension is too tight on the stitches and rolling in" (Olivia) were some

Table 2 Phase 2 (fit model interviews) participants

Fit model pseudonym	Sex	Size	Years of industry experience	Full-time /part-time	Recruited via/ at	Clothing categories the fit models fitted
Olivia	F	Medium	15+years	Full-time	Personal contact	Casual wear, formal wear, evening gowns, PPE, luxury ready-to-wear (runway), swimwear, jeans, activewear (all seasons)
Emma	F	Plus	2 years	Part-time	Personal contact	Plus size casual wear, formal wear, intimates (all seasons)
Ava	F	Medium	15+years	Full-time	Snowball sampling	Casual wear, formal wear (all seasons)
John	M	Medium	14 years	Full-time	Personal contact	Casual wear, formal wear, jeans, activewear, sports gear, swimwear (all seasons)
Luna	F	Medium	14 years	Full-time	Snowball sampling	Casual wear, formal wear, jeans, activewear (all seasons)
Mia *	F	Medium	5 years	Part-time	Company observation session (phase 1)	Wovens business casual (e.g., jackets, shirts, shorts, slacks, and joggers) (all seasons)
Liam*	M	Medium	2 years	Part-time	Company observation session (phase 1)	Wovens business casual (e.g., jackets, shirts, shorts, slacks, and joggers) (all seasons)

* Fit models, who participated in phase 1 data collection

of the comments that the fit models elaborated on during the interviews. How accurately the fit models can sense the garment fit could be related to their knowledge, skill levels, and years of expertise in the field. For example, Ava shared her experience as being a 'very precise tool' of fit testing as follows:

> *I know this is kind of a bragging statement. But I remember working with one of my last clients and you know, tried the garment on and I said you know, I think this is like an eighth of an inch off. Because did you check the specs on it? And they look at the paper and they go 'oh my god'. So, I was really proud that I just had this very tactile ability.*

In subcategory 2, comfort comments refer to the wear comfort whether the garment stayed in the right place when worn or whether it allowed the wearer to move freely. The fit models also exemplified some cases during which they did "a hug test" (Emma) to test the mobility of a jacket and armhole area. Additional placement comments included in this category explained whether zippers, pockets, buttons, and additional functional elements were in convenient spots where wearers could easily utilize them. One of the examples was "pockets work great, location and size" (Liam) while the fit model simulated putting his cell phone into the pocket to explain the placement and movement

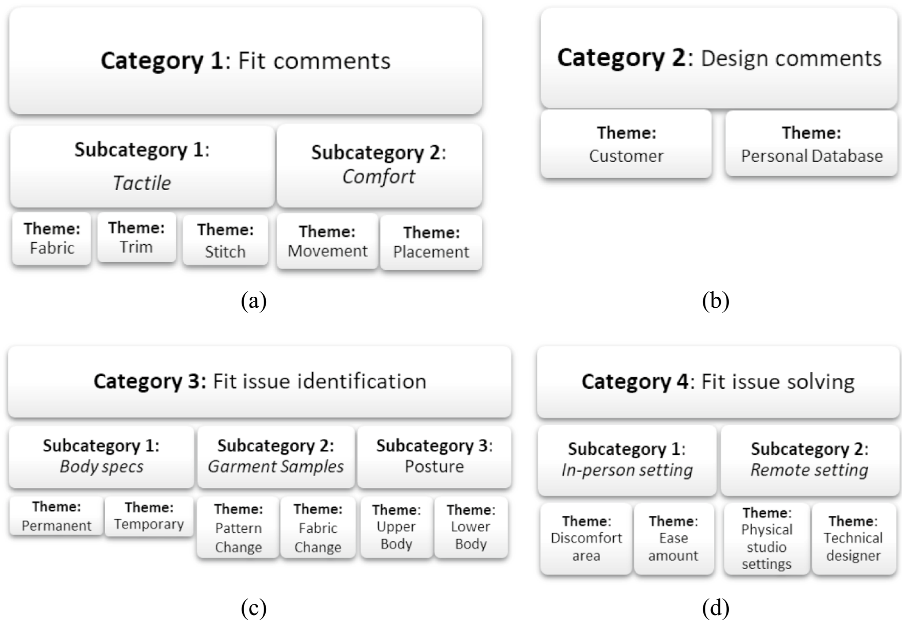

Fig. 2 The hierarchical trees of themes for **a** Fit comments/ feedback from fit sessions and fit model interviews, **b** Design comments related to fit models' points of view., **c** The clues that fit models use when identifying fit issues, and **d** Fit models' fit issue problem-solving based on fit session settings

adequacy at the same time. Although some tactile comments, such as "the fabric is soft enough that it is not irritating my skin", may not be easily replicated in 3D simulations, feedback related to "placement" can be integrated into 3D simulations to improve the success of the garment design and fitting. Avatars can move 360 degrees in every joint, but humans have some limitations. Fit models' comments on the placement of elements such as pockets or zippers that are difficult to reach can be collected. The accumulated data would help determine the right angle, depth, or length that wearers could reach and use. Such data would increase the efficacy of 3D garment fits and serve as a guide for designers to add practical features to clothing.

The second category was 'Design comments' (Category 2). Fit models elaborated on how their feedback was significant as they were the first 'Customers' trying on new garments and how they gained aesthetic insights and built a 'Personal database' while working in the fashion industry (Fig. 2b).

Olivia, Ava, and John, who were in the industry for over 14 years as full-time fit models gave detailed examples of how they provided design comments. 'Customer's point of view (POV)' and 'how to wear' were some of the descriptive codes, which were included in the theme 'Customer' after pattern coding. When fit models share their ideas referring to the 'length of garments', it was based on their 'Personal database' (Fig. 2b). Given that the full-time fit models had clients of 25 apparel brands on average, they have been seeing and trying greater numbers of clothing than average customers, junior technical designers, and/or designers. Unlike designers or technical designers, who work in-house or work for only a few brands at a time, fit models work for multiple brands at the same time serving as "the first customer of the garment" (Olivia). John explained the reason why a fit session team asks for design comments as follows:

> *It is not my job to give design feedback … But inevitably, people start asking me, and designers start asking me for validation about their design ideas and things like that … one of the strange things about being a fit model is that, like, you got up every day, and went to the mall, and walked through every store in the mall and tried on everything in there. And you just did that every day all day. That's basically what I do. I fit for 30-40 brands. But every 30-40 brands they are bringing in 10-15 different reference styles. And so, I literally see everything in the market, plus see what everybody's planning to do a year or two from now. So, there is some design knowledge there, I would say, but you don't want to cross lines with intellectual property … But like, over time, I have come to realize how aware I am of design, even though it is not part of the job.*

Olivia's 'design comments' (Fig. 2b) were to give feedback as a customer that some garments can be made easier to wear as indicated below:

> *I am like a regular customer who just goes in and like 'How does this work?' So, if I'm back in the fitting room for 10 minutes, and like 'I don't know how to put this on!' Those swimsuits, Oh my gosh, there's so many straps. I don't know what goes where. And so that's important for me to come out and be like yes, if I can't figure this out and you guys are taking 10 minutes, then how is the regular person going to figure this out?*

Fit models' comments revealed that their knowledge can overlap with that of designers. While discussing design aesthetics, they use their work experience of wearing numerous garments. The major difference between dressing bodies in 3D simulations and physical settings is the formation of garments. In a 3D CAD program, pattern pieces are placed on the corresponding body parts of the avatars and then sewn digitally (Magnenat-Thalmann, 2010). For example, sleeve patterns are placed on the arms and the front bodice pattern piece is placed on the chest of the avatar. However, physical garment patterns are sewn first and then garments are worn by pulling them down from the head or pulling them up from the feet. The present study findings highlighted the importance of the dressing process. Potentially, future studies can document the variety of motions and provide technical designers with specific information to predict fit issues in advance related to the effect of the dressing process on garment fit.

In conclusion, feedback types provided by fit models were found to be related to garment fit and design. Fit comments pointed out where and how they feel discomfort (Fig. 2a). Tactile feedback regarding fabrics, stitches, or trims was available only when garments were worn on the body. During fit sessions, fit models analyze the garments themselves by moving their bodies and identifying whether each element of the garment serves its purpose. For example, the location of openings or pockets should be convenient and intuitive as well as aesthetically pleasing for wearers. Fit comments delivered by fit models verified if garments were useful, protective, and fit well. Design comments were based on the fit models' database or knowledge that was accumulated over years of experience (Fig. 2b). During the interviews, experienced fit models, who have seen and worn more clothes than junior designers, provided detailed design comments explaining how they naturally became aware of designs and how they should fit because of working for many brands on the market. Additionally, the findings indicated that as they give design comments, they also look at the garment fit from customers' perspectives.

Processes to identify and solve fit issues (RQ2)

Pattern coding revealed two categories, 'Fit issue identification' (Category 3) and 'Fit issue solving' (Category 4). 'Fit issue identification' had three subcategories, 'Body specs', 'Garment samples', and 'Posture', and explained the mechanism through which fit models can pinpoint fit issues. The themes that were identified for 'Body Specs' included 'Permanent' and 'Temporary', the themes under'Garment samples' were 'Pattern change' and 'Fabric change', and the themes under 'Posture' were 'Upper body' and 'Lower body' (Fig. 2c).

John gave fit comments based on his body specifications, which were summed as subcategory 1 'Body specs' (Fig. 2c), because he remembered all his body measurements, which hardly changed, and thus stayed 'permanent' (Fig. 2c), over repetitive fit sessions. However, two of the female participants indicated menstruating as a 'temporary' (Fig. 2c) factor that affected body measurements with a comment such as, "As a woman, feeling a little full today" (Olivia). 'Body specs' (Fig. 2c) showed how precisely the fit models understood their bodies and used their knowledge as a baseline to evaluate the fit of garments. The theme, 'Permanent', emphasized how the fit models made comments based on their original physical features. John mentioned that he usually used his arms as a ruler as follows:

> *The arm length is a huge one. ... And I know that 33 and a half is right there (pointing at the part on his arm near his wrist). And I know where all those sleeve lengths hit. And I know where the averages are.*

Another way the fit models identified fit issues was by comparing the new samples with the samples they tested before and recalling their experiences. In subcategory 2 (Fig. 2c), i.e., 'Garment Samples', themes 'pattern change' and 'fabric change' refer to fit models' comments based on their repetitive fit assessments in identical brands. After several rounds of fit sessions, garment fit changes due to pattern alterations. Fit models remembered how each garment fitted in the previous session and compared the new sample with the previous sample. For example, fit session team members asked fit models, "Do you remember how the last one felt like?" (Kai) and had them compare new samples with the previous samples. Typically, apparel brands sell a few selected garments throughout multiple seasons if they are sold well. Based on the season that they are released; designers only change the fabrics of the garments. Fabric properties affect the fit of garments although they are constructed from the same patterns. If fit models work with the brands for several seasons, they could remember the tactile experience of the same garment made from different fabrics.

Under subcategory 3 (Fig. 2c), 'Posture', codes such as 'stand', 'sit', 'squat', 'lunge', and 'arms up', which represented fit models' movements, were grouped based on the body parts the fit models were moving. As fit models had their expertise in fitting various garments such as activewear, evening gowns, and lingerie, how they moved during fit sessions was diverse. For tops with sleeves, such as jackets and shirts, all fit models replied that they raised their arms to test the fit comfort (Fig. 3a). Moreover, fit testing with arm

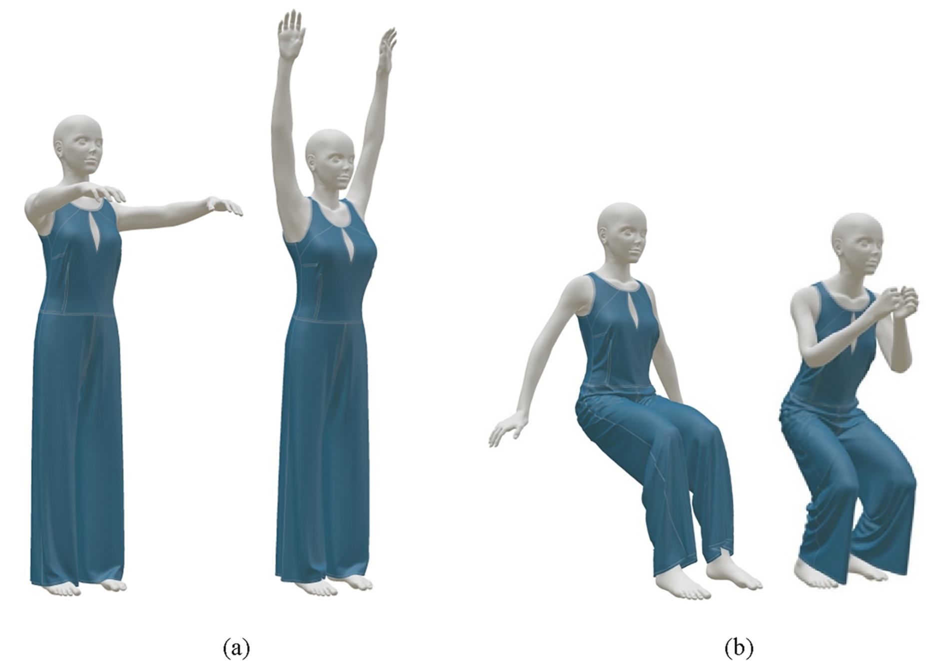

Fig. 3 The initial postures that fit models demonstrated during the observation and Zoom interviews were visualized in Browzwear VStitcher, as no pictures were taken during data collection. **a** Avatars with arms up to replicate fit models' movements as demonstrated, **b** Sitting (left) and squatting (right) postures to assess the fit of bottoms

movements was found to be essential in women's bras or swimwear fittings, for garments without sleeves (Fig. 3a). Codes, 'sit', 'squat', and 'lunge', under the theme 'Lower body' were related to fit testing of bottoms. Two common postures identified were sitting and squatting (Fig. 3b). Olivia and Ava stated that sitting was necessary to check if dresses were short in length and understand where the hem would be when sitting. On the other hand, 'squat' and 'lunge' were found when assessing the fit of activewear which were designed to promote athletic performance. The movements were intended to examine whether the garment served its purpose. Fit models made several initial movements to evaluate the fit of bottoms but the purposes behind each posture varied. Current virtual avatars in 3D simulations are not soft avatars that replicate the fat distribution or mimic the elastic changes of human skin upon various postures (Balach et al., 2021; McDonald et al., 2023). The present study underscored some of the key movements that fit models hold during fit sessions to identify fit issues. Although 3D simulations enable virtual avatars to move every joint in 360 degrees, identifying how body parts and surface skin change in the key movements would be a starting point for improving 3D simulations to provide reliable fit results.

For the 'Fit issue solving' category (Category 4), the identified fit issues varied depending on the fit session settings, i.e., in-person or remote, which became popular during the COVID-19 pandemic. How fit models provided solutions differed between the settings (Fig. 2d). In in-person settings, some experienced fit models gave comfort comments which were a combination of 'Discomfort areas' (Fig. 2d) that they were experiencing with the 'Ease amount', which would be needed to fix the discomfort. For example, "the front armhole feels like it's diving into my arm, and I feel like I need about half an inch more front saddle" (Luna). She pointed out the front armhole as a 'discomfort area' (Fig. 2d) and added comments that the front armhole had to be lowered half an inch.

Fit models who performed fitting sessions remotely included Olivia, John, and Luna. They were full-time fit models during the COVID-19 pandemic. They emphasized the importance of 'Physical studio settings' (Fig. 2d) they had for remote fittings such as "the correct color temperature of lights, it's 5600 overhead bar lights, I have front-facing LED light panels… I had a $7,000 camera, and my iPad as a mirror" (John) and "we used Zoom. I had like two or three spotlights set up. And I had two different cameras, that you had a clip, I had a close-up camera that I could use to show detail. And then I had a camera that I would set for the entire landscape" (Luna). Besides the lights and cameras, fit models also had full-length mirrors, clothing racks, steam irons, scissors, pins, seam rippers, tape measures, and sewing machines right next to them in the studio where they had remote fittings.

The theme, 'Technical designer' (Fig. 2d) referred to the fit models' practice of fitting and pattern alterations based on their technical knowledge when a technical designer is not in the same environment. On top of giving fit feedback, they ironed, pinned, cut, and marked the garments as delivering fit solutions. John explained the process as follows:

> *I am a half-assistant tech designer at this point… I will be like, you know, making adjustments and pulling things… And maybe not all fit models are capable of being like, Oh, this is where you pin, you know, or I need to cut it. Like, I will cut things and let them drop and do things like that.*

While assessing garment fit, fit models suggested solutions to fit issues as well which were considered technical comments. Luna described the process as follows:

> *I took on the role of the tech designer, I basically became a technical designer while I was doing that. So, you have to not only take notes and communicate with your factories, or your pattern makers, but you also have to pin and mark on the garment so that they know exactly where what part of the garment you're talking about. So, it is about creating that physical mark on the garment that you have to put on. In order to show exactly what sleeves you are talking about in the garment. So, I was doing it. Yeah, it was very much more technical design … I think I have been doing it long enough. I kind of did like three people's jobs in one and I was ready to take on the job.*

The current research underlined the plausibility of quantifying and expressing the pressure applied to different body areas using fit models' comments. Moreover, the necessary ease amount identified by fit models in fit assessments can be systematically recorded and used as a foundation in subsequent fit sessions to 3D simulations. If future studies gather data on pattern adjustments related to a specific amount of body pressure, the associated pressure maps could serve as a more precise tool for analyzing fit.

Fit models reported that they identified fit issues by using their bodies as precise tools to evaluate garment measurements (Fig. 2c). They remembered the garment fit of each fit session to refer to the fit of new samples. Moreover, they developed specific postures to examine garments such as skirt lengths. Fit models understood that the fit of garments that share the same design would be different if they were made with different fabrics. They were able to recall fit information from previous seasons and comment on fit differences driven by fabric differences. When they found fit issues, they provided solutions for them by stating where they occurred and how to fix them (Fig. 2d). During in-person fit sessions, the conversations revolved around discomfort areas and suggested ease amounts. When they operated remote fit sessions, for example during the pandemic, they made sure that fitting room settings were well-prepared for Zoom calls as well as conducting garment alterations while taking the technical designer role and fitting garments.

In short, the study findings indicated that there were four primary roles fit models held in fit sessions. First, they were live models who could give tactile and comfort comments about sample garments. Second, they had technical knowledge related to pattern alteration when discussing where and how much additional ease to add. Remote fit sessions during COVID-19 were viable due to the technical knowledge that fit models already had. Considering technical suggestions were regarded as significant or accepted as final pattern alterations, fit models had technical design knowledge and performed with the knowledge during fit assessments. Third, their knowledge, which was collected over years of experience, enabled them to take technical designer and designer roles. Fourth, they were the first customers of mass-produced garments and were able to provide customers' points of view. They commented not only on their experience of wearing the garments but also on their experience of putting them on and taking them off.

To better connect the feedback collected from the fit models with quantitative indicators, the present study guided what should be documented in future studies to improve 3D simulations and eventually better utilize them in fit assessments. The ranges of motion, key postures, and fit alteration comments based on the amount of pressure on fit models' bodies can direct how avatar rigging and 3D simulations can be improved to support fit sessions. Even though 3D avatars are not human beings, a detailed database of fit models' experiences can be developed to acquire some fit experience predictions.

The present study had limitations in that the number of fit models and technical design teams recruited was small. Additionally, the limited number of fit models that were recruited for the study may not provide extensive details in certain garment categories such as snow clothes; but the years of experience and number of brands each fit model was participating in provided sufficient details related to fit sessions in most categories of garments. While the study findings cannot be generalized, our findings identified a room to improve technologies to support fit sessions when using virtual fitting in 3D CAD. For instance, the poor fit that appears when fit models move is one of the most essential comments in fit sessions. In the current study, it was also found that fit models' comments of where and how to fix the area when garments were 'digging in' instead of 'feeling snug' were valid. The amount of pressure that the body parts sense can be translated into the amount of extra ease that fit models and technical design teams would agree on. The pressure map tool in 3D simulations currently does not represent the actual pressure the wearer is experiencing (Brubacher et al., 2023; Zangue et al., 2020). Therefore, it is still not ready to be used as a direct communication tool that indicates the level of discomfort the wearer feels. In 3D CAD programs tools such as stress, pressure, and strain maps use color-coding to show the tightness of the garment. However, it is challenging to interpret the colored maps and guess how tight the actual garment would be (Zangue et al., 2020). The present study suggested that the amount of pressure on each body part could be captured, thus supporting tools such as pressure maps to serve as a fit analyzing tool with higher accuracy. Additionally, the extra ease amount that fit models identified during fit assessment can be tracked and accumulated as a baseline in fit test sessions to improve digital avatar offerings.

Future studies should also hold in-depth interviews with fit models with fit specialties in various types of clothing and identify movements or postures developed to assess certain garments. Muscle, joints, and fat distribution changes from the movements and corresponding garment placements could explain more of fit. Avatars should be improved based on how the body changes when squatting, sitting, and lifting arms to improve fit assessments when using 3D simulations. As shown in Fig. 3, four postures were identified throughout the present study, and there might be other postures to be found in future studies if the studies focus on fitting specific types of garments that were not included in the current study.

Conclusions

The fashion industry aims to digitalize the entire process of design and production of garments to enhance its sustainability efforts as the digital workflow can reduce the number of prototypes. Currently, new styles are designed and draped on avatars in 3D CAD programs for fit testing. Even though parametric, body scan, and soft avatars can be useful in understanding garment fit in software programs to a certain degree, there is still room to improve 3D software offerings for technical designers. Investigating how fit models perform in physical fit sessions is one step toward improving fit assessments in 3D simulations. In repetitive physical fit sessions, fit models' comments help finalize garments to be manufactured for the market. Despite their importance, the role of fit models in this process has not been thoroughly studied due to the secrecy of fit sessions and the confidential nature of discussions about unreleased products. In the present study, we conducted an onsite observation with fit models to capture how they perform in the fit session settings. In addition, individual interviews were followed with fit models to understand their interpretation of the garments and to collect their knowledge. The findings uncovered the types of feedback fit models provide, and the process through which fit models identify fit issues and propose solutions. They brought their knowledge and tactile reviews to discuss with the team as live fit models, which were irreplaceable in fit sessions, but also had ample knowledge that intersects with that of technical designers and designers. Practical applications of the findings would include incorporating accurate representation of 3D virtual avatars with the key movements that fit models use to test the fit of garments, identifying the range of natural motions of human bodies to validate the location of garment details such as pockets or zippers, integrating dressing process in simulations to avoid potential design flaws, and improving pressure maps with realistic, quantified ease amount suggestions. The findings of this study could benefit the apparel CAD technology development, fostering the provision of well-fitted garments. Repetitive fit sessions with excessive garment samples can be simplified due to 3D software after they are updated with the findings that indicate how fit models identify fit issues and participate in fit sessions.

Author contributions
YY and FB designed the study. YY conducted data collection and analysis and wrote the manuscript. FB supervised the research design, guided manuscript writing, reviewing, and revising, and supervised the overall project. Both authors read and approved the final manuscript.

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Availability of data and materials
All data is available via the Fashion and Body Tech Lab and archived electronically on Cornell Box.

Declarations

Ethics and consent
This study was approved by the Cornell Institutional Review Board for Human Participants (Approval No. 210801049).

Competing interests
None of the authors have any competing interests.

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