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A Comparative Analysis between Real and Virtual Stretchable Tight-Fitting Clothing

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Abstract In order to expand the utilization range of 3D virtual clothing systems in the field of tight clothing, this study attempted to provide more in-depth research data to confirm the utility of CLO software in the field of tight-fitting clothing by comparing and evaluating the appearance similarity of 3D virtual clothing. In this study, the target outfit is selected as a basic short-sleeved top (Garment 1 without lining and subsidiary material), basic short-sleeved top with lining (Garment 2), chest cap (Garment 3), and chest cap (Garment 3-1) to determine the similarity among factors that may affect the appearance similarity of 3D virtual clothing. The costume pattern was digitized into YUKA CAD, the real fitting body was implemented in CLO through the 3D scan, and a 3D virtual image was produced. Then, Garments 1 to 3 were photographed and analyzed by evaluating the similarity between real and 3D virtual images on a 5-point scale to 10 experts. The results of this study are as follows. First, on evaluating the similarity between the real and 3D virtual images of Garments 1, 2, 3, and 3-1, the garments were seen that the implementation of lining insertion was similar and well-executed. There was no significant difference in the evaluation score of all garments to affect the usefulness of the CLO, although the difference between the evaluation scores of all garments was not significant, it was noted that the score of Garment 3 was the lowest, followed by Garment 3-1.

Keywords 3D virtual clothing system, 3D digital fabric, Fourth industrial revolution, Tight-fitting clothing, Stretch fabric

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Introduction

In the fashion industry as well, digitization is increasingly being carried out in the production of clothing products using information and communications technology (ICT). Apparel computer-aided design (CAD) used for pattern development such as grading and marking, in addition to pattern production, is now being expanded to 3D virtual clothing simulation (Choi, 2018). In particular, the 3D virtual garment simulation technology, introduced as a core technology that can greatly change the way the clothing industry operates, helps carry out the clothing product development process in virtual space by performing virtual fitting model creation, pattern production, design deployment, textile placement, colorway, artwork image mapping, size deployment, and pre-fit sample production and editing using computers (Oh & Ryu, 2015). Furthermore, fabric drape, textile design, and color combinations can all be checked together using

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computer graphics, which makes it possible to suggest an overall trend in clothing products (Ju & Jung, 2016). Hence, the introduction of the 3D virtual clothing system is expected to boost revenue by opening the door to more interesting and diverse marketing than before. For example, it is expected to lead to better communication between foreign buyers and partners, rapid development of more accurate sales plans that reflect consumers' needs, virtual reality (VR) stores, augmented reality (AR) showrooms, and holograms (Yoo, 2021). The convergence of apparel fashion and 3D digital technology has replaced display garments in lookbooks and online shopping malls with 3D virtual garments (Yoo, 2020). Likewise, as contactless fashion consumption activities are on the rise, and because it is becoming important to use technology that customizes fashion services to align with consumer behavior and preferences, it is critical to implement 3D virtual garments as realistically as possible. To introduce and expand the use of the 3D virtual clothing system, it is important to develop technology that minimizes gap between real and 3D virtual garments while continuing to obtain the validation data of virtual outfits as an alternative. Accordingly, prior research on 3D virtual clothing software has been conducted from various perspective moss. Lee (2020) suggested the pattern correction method according to the fabric thickness of the female tailored jacket was compared with the 3D virtual costume using CLO software. Kim, Uh, and Hong (2015) suggested perspective and appearance evaluation of real and 3D virtual costumes was performed on men's slim fit pants, and clothing pressure by posture was measured and analyzed using the stress distribution function of CLO software. There are many factors contributing to the accurate virtual simulation of garments, including fabrics, subsidiary materials, seam allowance, and sewing thread. Since fabrics are an integral part of clothes, Lee and Kim (2011) suggested that it is becoming increasingly necessary to research the physical properties of virtual and real fabrics in order to expand and improve the 3D virtual clothing system. The biggest challenge in replacing pre-fit samples with 3D during tight-fitting clothing development is that various subsidiary materials are inserted into tight-fitting clothing. While these subsidiary materials have a large effect on garment appearance, there are few studies on the perfect 3D modeling of tight-fitting clothing inserted with subsidiary materials. Hence, more studies are required to model virtual garments as realistically as real garments (Lee, Lee, & Hong, 2016). Since tight-fitting clothing is stretched to put on, it is more influenced by tension depending on the thread and sewing technique. Furthermore, the current 3D virtual clothing software cannot implement a soft fitting body, and therefore, it has a limitation that it cannot reflect the shape of the pressed and modified skin when tight-fitting clothing is put on. In the future, the 3D virtual clothing system could be used in several ways for athleisure wear and swimsuits (e.g., for creating pre-fit samples before mass production or for display in online stores offering custom-made garment production). However, to achieve that it is crucial to advance 3D virtual clothing technology through continued research. Specifically, it is important to research solutions for: producing highly realistic 3D virtual fabrics that accurately mimic the way real fabrics interact with the human body, and reducing the visually perceptible difference between real garments inserted with subsidiary materials and their 3D virtual counterparts.

Therefore, to help expand the use of 3D virtual clothing system to tight-fitting clothing, this study was conducted to confirm the effectiveness of CLO in tight-fitting clothing by comparing and evaluating the appearance similarity between real and 3D virtual tight-fitting garments produced using the CLO virtual clothing software, and at the same time, to serve as a reference for a more in-depth study such as a study on the direction of improvement on the factors that cause differences in the future to make 3D virtual tight-fitting garments more realistic.

Method

Sample Selection

In this study, CLO software, which is most widely used in domestic fashion companies and universities, was used. This study intends to confirm whether the insertion of the lining and breast cap, often used in female athleisure garments, are represented realistically among other elements that may contribute to an appearance gap with real garments when tight-fitting garments are recreated as 3D virtual garments.

The clothing sample was selected based on reference to previous studies and flagship items in tight-fitting athleisure brands. Referring to a previous study (Lee & Lim, 2021) on athleisure wear worn by Korean women, this study chose a type of t-shirt that had the highest purchase rate among other athleisure wear items. According to Jun and Jang (2018), who studied the production status of tight-fitting female sportswear products, the round neckline accounted for 73% of the tight-fitting clothing products. Lee, Choi, and Do (2017) reported in an athleisure design preference survey on women in their 20s that most respondents (32.3%) preferred the round neckline. Based on these findings, the round neckline was selected for the sample garments. According to Lee et al. (2017), in the production status of types of sleeves, sleeveless accounted for the highest percentage at 54%, but this study chose short-sleeves, which showed the second highest percentage to compare the shape of the sleeve. Furthermore, considering the finding that in terms of the designs of tight-fitting female athleisure tops, Lee et al. (2017) also reported products combining meshes accounted for 65% and products with two layers of detachable breast pads with the mesh lining on top of the breasts accounted for 35%, this study chose the design with the lining and breast cap for the clothing sample. Regarding the composition of fabrics in female sportswear tops, 75-100% are made of polyester, 75-100% use nylon, and 10-20% are made of polyurethane. Fabrics in sample garments were chosen within these composition percentages (Jun & Jang, 2018).

Accordingly, this study evaluated the following four garments: Garment 1 - a short-sleeved top without lining and with a round neck (Figure 1); Garment 2 - a short-sleeved top with lining (Figure 2); Garment 3 - a short-sleeved top with lining and breast cap (Figure 3); and Garment 3-1, which was same as Garment 2, with the only difference being that it was put on the fitting body after attaching the breast cap to the fitting body. In addition, this study chose designs that did not have rubber bands, interfacing, and wires inserted in fabric finishes that cannot digitize the properties of the CLO fabric kit. Regarding fabrics, Garment 1 had the composition of polyester 92% and polyurethane 8%. Garment 2 had nylon 82% and polyurethane 18%. Garment 3 and Garment 3-1 had the same fabric as Garment 2 but with the breast cap inserted.

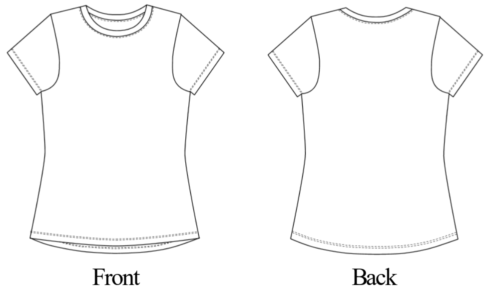


Figure 1. Tight-fitting cloth without lining (Garment 1)

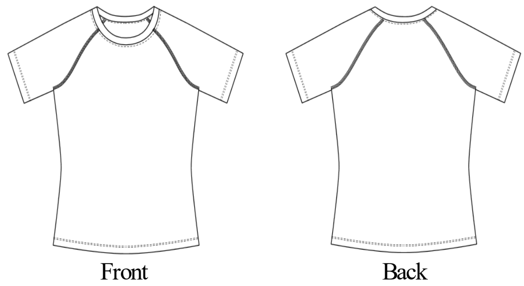


Figure 2. Tight-fitting cloth with lining (Garment 2, Garment 3-1)

Figure 3. Tight-fitting cloth with lining and breast cap (Garment 3)

Digitalization of the Sample Fabric

Three sample fabrics were digitalized: the main outer fabric used in Garment 1 (Fabric A); main outer fabric used in Garment 2, Garment 3, and Garment 3-1 (Fabric B); and mesh lining fabric (Fabric C). Real fabric physical properties were measured, and the measured fabric physical properties were entered and digitized in Emulator in CLO software. The measured physical properties included weight, thickness, bending, and stretch-stiffness. Equipment used to measure real fabrics was a CLO fabric kit developed by CLO Virtual Fashion, which is currently used most widely by fashion companies and educational institutions in Korea (Figure 4). Validity and limitation of the property values measured with the CLO fabric kit is verified in the previous study. A study on the improvement of the reality of tight-fitting elastic virtual garment (Kim, 2022). Fabric physical properties measured by the CLO fabric kit included weight, thickness, bending, and stretch-stiffness. A fabric swatch was 22 cm*3 cm in size, tailored in the weft, warp, and bias directions, and the above fabric physical properties were measured in the weft, warp, and bias directions.

Figure 4. CLO fabric kit components

A scale to measure the weight of the fabric swatch; 3 swatches in the weft, warp, and bias directions were all placed on the scale, and the measured weight was entered as weight (g) in the Emulator. Among other fabric physical properties calculated by the Emulator, density represents weight per unit area. The measured weight value is converted and displayed. A tool that measures fabric thickness; one of the fabric swatches was placed below the gauge, the metal lever at the top of the tool was pressed, and thickness indicated in the gauge was entered as thickness (mm) in the Emulator. Thickness is shown as measured without unit conversion. A bending test device, which measures bending in each of the weft, warp, and bias directions. The fabric swatch on the plate was gently rolled with the roller to allow the fabric swatch to naturally bend and go down with gravity from the edge of the plate, and the location in contact with the end of the fabric swatch was entered as rolled distance (mm). The fabric length ruler was placed under the rolled fabric to measure the length of the fabric, which was used as length (mm). Values measured by the bending test device were converted into bending stiffness-weft, bending stiffness-warp, and bending stiffness-bias. The value measured with the swatch tailored in the weft direction was converted into the bending stiffness-weft value, the value measured with the swatch tailored in the warp direction was converted into the bending stiffness-warp value, and the value measured with the swatch tailored in the bias direction into the bending stiffness-bias value.

A stretch test device, which measures stretch-stiffness in each of the weft, warp, and bias directions. The fabric swatch was placed on the plate, screws were tightened from both ends to secure the fabric, and then the lever was rotated to pull the fabric at certain length intervals and measure the force on display depending on the length. Values measured by the stretch test device were converted into stiffness-weft, stretch stiffness-warp, and bias elasticity (shear) among other fabric physical properties.

Emulator has 4 types of fabrics: knit, woven, leather, and silk and synthetic silk. Since the type of fabric affects fabric physical properties, the same measured value may lead to a different converted property value depending on the type of fabric. Another physical property was buckling. Buckling is indicated in the range of 0 to 1, it refers to the tendency of a stable fabric to bend when a certain level of force is applied. The buckling ratio is designated as 0.30 for weft, warp, and bias; buckling-stiffness is designated as 0.25 for weft, warp, and bias. For knit, leather, and silk, they are all designated as 0.

Digitalization of the Fitting Body

For the fitting body used to put on real and 3D virtual garments, this study used a fitting body produced by Fit & Body based on analysis of data from Size Korea in 2004. As the sample garments had short sleeves, a body with detachable arms was used. Table 1 lists the size specifications of the upper fitting body.

Table 1. Measurement of the real fitting body and the virtual fitting body scanned by Artec Eva

unit: cm

	Measurement items	Real fitting body	Virtual fitting body
1	Bust Circumference	82.5	82.8
2	Underbust Circumference	72.0	72.3
3	Waist Circumference	65.0	65.4
4	Top-hip Circumference	76.6	76.8
5	Hip Circumference	91.0	90.7
6	Chest Circumference	84.3	84.6
7	Upper-Arm Circumference	22.7	23.1
8	Waist-Back Length	38.0	38.0
9	Front-Neck Point to Waist Length	32.3	32.3
10	Side Neck Point to Bust Point Length	25.0	25.0
11	Bust-Point Breadth	15.7	15.7
12	Across Back Shoulder Width	40.0	40.1
13	Waist to Hip Length	23.0	23.0

3D scanning was used to create the same shape in a 3D obj, and it was imported into CLO software(Table 1). The Artec 3D scanner, which is suitable to precisely measure a mid-size object, was used for scanning. Artec Eva, which was used to scan the fitting body of Artec 3D equipment, is a white light technology-based handheld scanner that accurately measures medium-sized objects over 10cm in high resolution. Based on structural light scanning technology, Artec Eva has a maximum accuracy of 0.1 mm, a maximum resolution of 0.2 mm, and a 3D reconstruction ratio of 16 fps. As a result of comparing the sizes of the real fitting body and the virtual fitting body, the circumference item had a difference of less than 4mm and the length item had a difference of less than 1mm, which was very accurately implemented.

There were two fitting bodies used: Fitting Body 1, which was computer-generated by 3D scanning and digitizing the real fitting body, and Fitting Body 2, which was computer-generated by 3D scanning and digitizing the real fitting body after the breast cap was attached to the body. For Fitting Body 1, the obj file created by 3D scanning the real fitting body was imported into Avatar in CLO. For Fitting Body 2, the obj file created by 3D scanning the real fitting body tightly fitted and attached with the breast cap along the line below the breasts was imported into Avatar in CLO.

Making the 3D Virtual Garment

To convert real garments into 3D virtual garments, it is necessary to digitize patterns in real garments. YUKA CAD, which is used by most clothing businesses in Korea, was used as 2D pattern CAD for digitization, and Digitizer was used for vectorizing. Garments were deconstructed by pattern, turned into 2D, entered into Digitizer, and then converted into a dxf file in YUKA CAD to be compatible with CLO.

3D virtual garments were computer-generated by CLO from CLO Virtual Fashion. 2D pattern data completed by YUKA CAD was converted into a dxf file, imported into CLO, and placed into a digital fitting body with 3D scanned patterns, and then the patterns were virtually sewn in CLO based on real garments. Digitized fabrics were applied to one main outer fabric for Garment 1 and one main outer fabric and one lining fabric for Garment 2, Garment 3, and Garment 3-1. The texture color, stitch, and logo were represented to complete 3D virtual garments.

Garment 2 had an elastic band (E-band) inserted in the hem of the lining, and a CLO fabric kit, which requires a swatch of a certain length tailored in the weft, warp, and bias directions, cannot measure the elastic band's physical properties and does not provide other conversion methods. Hence, CLO currently has no official formula or method to measure and implement the physical properties of the type of elastic band. Accordingly, the elastic band's bending -stiffness and stretch-stiffness were visually adjusted to be similar, and then the resulting square pattern whose length and height corresponded to those of the real elastic band was used. Garment 3 and Garment 3-1 used the same garment as Garment 2 with the breast caps added using different methods. The size of the real breast cap measured to computer-generate the breast cap in Garment 3 as a pattern in CLO and place it just like the real breast cap. The width of the real breast cap inserted into Garment 3 is 25 cm, and its height from its bottom to its highest point is 3.5 cm. The section of 1 mm in the thickness of the breast cap was categorized as “a” and the section of 8 mm as “b” (Figure 5).

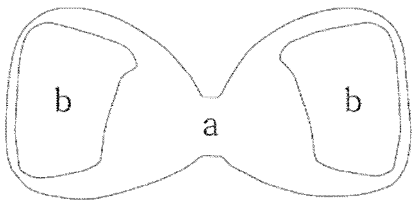


Figure 5. The schematic of the back of the breast cap

For the breast cap of the 3D virtual garment in Garment 3, a virtual breast cap computer-generated like the real breast cap with a width of 25 cm, volume thickness of 3.5 cm from the bottom, Section a of 1mm, and Section b of 8 mm was simulated in the same location as the real breast cap, inside the 3D virtual garment and below the breasts of the fitting body.

For Garment 3-1, the breast cap was not implemented during the creation of the 3D virtual garment in CLO, but the fitting body with the breast cap already attached was digitized and implemented. Given that Alvanon, a global fitting body production firm creates and provides infant avatars with the volume of infants wearing diapers as a standard avatar(Alvanon, 2022), the breast cap was tightly fitted below the breasts of the fitting body and then 3D scanned. The 3D virtual garment was put on the 3D fitting body with 3D scanned data imported into CLO. With these digitized fabrics and patterns, 3D virtual garments were created by CLO, and 3D virtual and real garments were put on the same body. Since the length, puckering, and silhouette of tight-fitting clothing can vary depending on how a person puts it on, it is important to put real and 3D virtual garments on in the same manner. Garment 1 with the shoulder line was put on with the shoulder line, side neck point, side line, shoulder point, and outfit hem locations aligned. Garment 2, Garment 3, and Garment 3-1 were put on with the side neck point, side line, and outfit hem locations aligned.

Evaluation of the Appearance of Real Clothes and 3D Virtual Clothes

Expert evaluation on the similarity between real and 3D virtual garments was made subjectively with photographs taken of the front, back, and right side of real and 3D virtual garments from the same distance of 1.2 m. The evaluation method in this study was similar to those used in Lee, Lee, Kim, and Kang (2011) and Kim, Yin, and Song (2014). A total of 12 clothing-related experts performed the evaluation. The criteria for inclusion as an evaluator was minimum two years of experience in the clothing business, experience in 3D garments, and master's and doctoral degrees in clothing with adequate understanding and knowledge of the field. After observing the photographed images of real and 3D virtual garments, they rated the similarity between them on a five-point scale with 5 points being the highest level of similarity. Similar to Lee et al. (2011), seven evaluation questions were included, and they covered seven aspects (Table 2). SPSS 23 was used for statistical analyses, and a multiple comparison test with one-way ANOVA and Duncan's test was used to compare the mean score by garment and question.

Table 2. Questions evaluating similarities between real garment and virtual garment

View point	Question
Front	Q1. Is the overall appearance similar?
	Q2. Is the length of the outfit similar?
	Q3. Are the length of the sleeves similar?
	Q4. Is the appearance of the neckline similar?
	Q5. Is the position and shape of the seam line similar?
	Q6. Is the shape of puckering similar?
	Q7. Is the appearance of the fabric similar?
Back	Q1. Is the overall appearance similar?
	Q2. Is the length of the outfit similar?
	Q3. Are the length of the sleeves similar?
	Q4. Is the appearance of the neckline similar?
	Q5. Is the position and shape of the seam line similar?
	Q6. Is the shape of puckering similar?
	Q7. Is the appearance of the fabric similar?
Side	Q1. Is the overall appearance similar?
	Q2. Is the length of the outfit similar?
	Q3. Are the length of the sleeves similar?
	Q4. Is the appearance of the neckline similar?
	Q5. Is the position and shape of the seam line similar?
	Q6. Is the shape of puckering similar?
	Q7. Is the appearance of the fabric similar?

* 5-point Likert scale: 1=very different, 2=different, 3=average, 4=similar, 5=very similars

Results

Results of the Digitalization of the Real Fabric

Table 3 shows the measured physical properties of Fabrics A to C entered into Emulator, digitized, and automatically converted in the CLO software. Fabric A is the only fabric used for garment 1, Fabric B is the main fabric used for the surface fabric of garment 2, and Fabric C is the mesh fabric used as the lining for garments 2, garments 3, and garments 3-1.

Table 3. The physical properties of five stretch fabrics in CLO

	Fabric A	Fabric B	Fabric C
Stretch stiffness-Weft (g/s^2)	14,596	56,355	31,360
Stretch stiffness-Warp (g/s^2)	14,043	49,476	63,014
Sheer stiffness (g/s^2)	4,110	5,220	16,552
Bending stiffness-Weft ($g{\cdot}mm^2/s^2rad$)	41	125	98
Bending stiffness-Warp ($g{\cdot}mm^2/s^2rad$)	50	176	119
Bending stiffness-Bias ($g{\cdot}mm^2/s^2rad$)	42	159	85
Density (g/m^2)	141.92	162.12	130.30
Thickness (mm)	0.60	0.45	0.40

A lower stretch stiffness indicates a higher level of stretchability. Fabric A had the lowest stretch stiffness value in the weft, warp, and bias directions, but had the highest level of stretchability. Fabric B had the highest level of stretch stiffness in the weft direction, while Fabric C had the highest level of stretch stiffness in the warp and bias directions. However, Fabric C exhibited the lowest stretchability. A lower measured value of bending stiffness means that the fabric is bent perpendicularly against gravity. Fabric A had the lowest level of bending in the weft, warp, and bias directions. Fabric B had the highest level of bending in the weft, warp, and bias directions. Fabric C had the second highest level of bending. Meanwhile, the density was highest in Fabric B, followed by Fabrics A and C. Thickness was highest in Fabric A, followed by Fabric B and C.

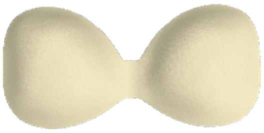
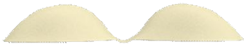
Results of the Digitalization of Fitting Body

Table 4 describes the real fitting body and digital fitting body based on the method of 3D scanning and digitizing the real fitting body as it is (Fitting Body 1) and the method of 3D scanning and digitizing the real fitting body after attaching the breast cap (Fitting Body 2).

Table 4. The actual fitting body and the two types of 3D scanning fitting bodies

	Actual fitting body	Digital fitting body
Fitting body 1		
Fitting body 2		

Table 5. A breast cap shaped into patterns from CLO

	Front	Side	Back
Real breast cap			
Virtual breast cap			

The obj file, which is the 3D object data generated from 3D scanning, was imported into the CLO. Among the import options, the object-type was implemented by importing it into the avatar. The digital fitting body without the breast cap and the digital fitting body with the breast cap were precisely implemented on the real fitting body for the sewing line, curves in the arm connections, and other shapes.

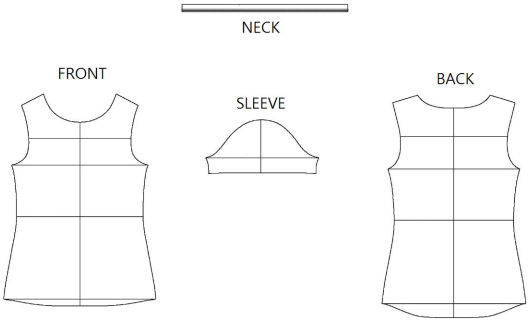


Figure 6. The pattern of Garment 1

Results of Computer-Generated 3D Virtual Garments and Clothing

Patterns from real garments were computer-generated using Digitizer and Yuka CAD. Figure 6 illustrates the computer -generated patterns for Garment 1, which consisted of four patterns, namely: front, back, sleeve, and neck ribs.

Figure 7 describes the computer-generated patterns in Garments 2, 3, and 3-1. As these garments had a lining inserted, the patterns in the main outer fabric and mesh lining

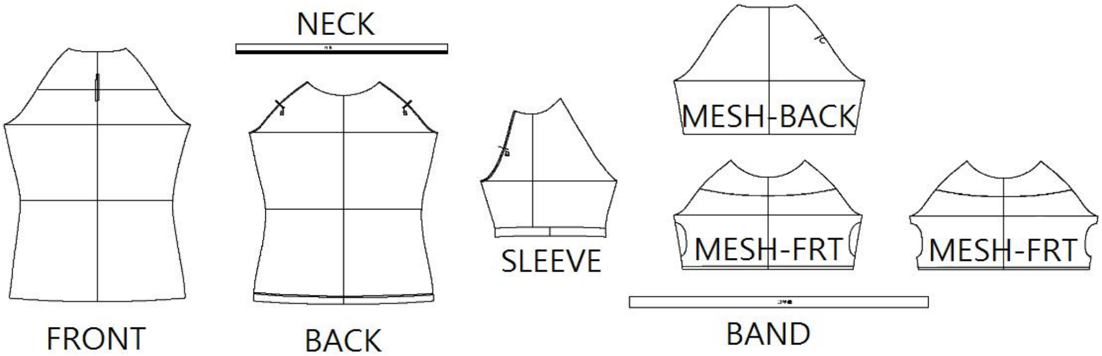


Figure 7. The patterns of Garment 2, Garment 3, and Garment 3-1

were all computer-generated. There were four main fabric patterns: front, back, sleeve, and neck ribs. The front consisted of two patterns: one in contact with the main fabric and the other with the side line cut for the insertion of the breast cap. The back showed one pattern. Although a pattern was not produced for the elastic band sewn to the lining hem during real garment production, the pattern was required for the implementation in CLO software. Hence, the elastic band pattern was computer-generated.

Table 5 illustrates the size and thickness of the real breast cap used in Garment 3, which was measured and shaped into patterns using the CLO software. The avatar is not soft and hard like the human skin, so it is not affected by the oval pattern inside the real breast cap at all, but only by the height. Therefore, the volume of the breast cap was divided into zones according to the height and expressed as a pattern.

It is impossible to measure the physical properties of the material used in a real breast cap. Hence, it was manufactured by adjusting the fabric properties in the CLO software to make it visually similar to the actual shape. Therefore, some differences were observed in the modified shape or degree of the breast cap when an external force was applied.

As the texture of the garments was implemented by inserting the image files of the real fabrics that were scanned, the fabric texture was visually implemented well, but the fabric transparency or light reflection was not implemented at all. Consequently, the material texture was represented by visually adjusting the light reflection in fabrics after putting the 3D virtual garments on.

Results of Evaluation of the Appearance of Real Clothes and 3D Virtual Clothes

Table 6 shows the front, back, and side images of real and 3D virtual garments in Garment 1, Garment 2, Garment 3, and Garment 3-1.

Real garments were put on after pulling the hem to the length where the front did not have puckering, and the side line was not tilted. 3D virtual garments were put on in the same way and then simulated after pulling the hem to the same length as the real garments.

In Garment 1, the side neck point of the virtual garment was stretched slightly during 3D simulation but the outfit length, sleeve length, puckering, and materials felt very similar to the real one. Puckering was thinner in the sleeves of the virtual garment. In Garment 2, the hem, neckline, and sleeves were stretched slightly during 3D simulation. Puckering and materials felt very similar to the real one. The turn back area was a bit loose around the sleeves of the real garment, whereas the virtual garment was tightly fitted to the fitting body. In Garments 3 and 3-1, while the necklines of both real and virtual garments were stretched more than Garment 2 due to the volume of the breast cap, that of virtual garments were stretched less than the real garment. Since the same volume was implemented for the breast cap, the side appearance of Garments 3 and 3-1 looked very similar. The front appearance of Garment 3 showed some difference as the shape of the breast cap did not remain intact due to the conflict between fabrics (since the breast cap was computer-generated and inserted as a pattern). Nonetheless, the size of the breasts was similar. It seems that the breast cap had flexibility and was naturally bent by the garment, resulting in a similar look to the real garment. As such, this method is not considered effective. Hence, in Garment 3-1 with the breast cap tightly fitted to the body and then 3D-scanned to use it solidly, the breast cap looked similar, but as the breast cap was not naturally modified by the force applied by the garment, the edge of the breast cap in the virtual garment looked more voluminous.

What was common was that the hem or neckline was stretched differently during simulation due to a different friction between the real fitting body and the digital fitting body. Due to the nature of the virtual garment, which did not reflect the seam allowance and sewing thread, thickness in seam allowance showed some difference, but there seemed to be no big difference in overall appearance.

Table 6. Comparison of appearance similarity between actual garments and 3D virtual garments

		Front	Back	Side
Garment 1	Actual garment			
	3D virtual garment			
Garment 2	Actual garment			
	3D virtual garment			
Garment 3	Actual garment			
	3D virtual garment			

Garment 3-1	Actual garment	
	3D virtual garment	

Table 7. Expert evaluation of the similarity between real garments and 3D virtual garments

			Garment1	Garment2	Garment3	Garment3-1	Ave.	F
Front	Q1	M	4.67	4.75	4.50	4.25	4.54	1.81
		SD	0.65	0.45	0.67	0.45	0.58	
	Q2	M	4.75	4.58	4.67	4.42	4.60	0.57
		SD	0.45	0.67	0.65	0.79	0.64	
	Q3	M	4.75a	4.83a	3.50b	4.67a	4.44	10.66***
		SD	0.45	0.39	1.00	0.65	0.85	
	Q4	M	3.83	3.92	4.00	3.75	3.88	0.20
		SD	0.84	0.79	0.84	0.87	0.81	
	Q5	M	4.67a	4.42a	3.33b	4.17a	4.15	7.40***
		SD	0.49	0.67	1.07	0.58	0.88	
	Q6	M	3.67b	4.67a	3.92ab	3.92ab	4.04	2.98*
		SD	0.89	0.49	1.00	1.00	0.92	
	Q7	M	3.50b	4.50a	3.92ab	4.00ab	3.98	3.07*
		SD	0.80	0.52	0.29	0.25	0.13	
Back	Q1	M	4.75	0.67	4.42	4.70	4.56	0.54
		SD	0.52	0.65	0.669	0.49	0.58	
	Q2	M	4.75	4.50	4.58	4.58	4.60	0.39
		SD	0.46	0.67	0.669	0.52	0.57	
	Q3	M	4.83a	4.83	4.75	4.50	4.73	1.53
		SD	0.39	0.39	0.46	0.52	0.45	
	Q4	M	4.25a	3.83	4.00	4.33	4.10	0.62
		SD	0.97	1.03	1.21	0.78	0.99	
	Q5	M	4.17a	4.42	4.42	4.17	4.29	0.41
		SD	0.72	0.79	0.67	0.93	0.77	
	Q6	M	3.25	3.50	3.58	3.67	3.50	0.38
		SD	0.62	1.67	1.67	0.99	0.99	
	Q7	M	3.42	4.33	3.92	4.08	3.94	2.69
		SD	0.79	0.65	0.90	0.90	0.86	
Side	Q1	M	4.42	4.83	4.42	4.33	4.50	1.66
		SD	0.67	0.39	0.67	0.65	0.62	
	Q2	M	4.67	4.58	4.42	4.33	4.50	0.49
		SD	0.49	0.67	0.90	0.89	0.74	
	Q3	M	4.58	4.58	4.33	4.25	4.44	0.58
		SD	0.52	0.52	0.99	0.97	0.77	
	Q4	M	4.58	4.67	4.42	4.67	4.58	0.32
		SD	0.79	0.65	0.79	0.65	0.71	
	Q5	M	4.33	4.75	4.42	4.58	4.52	0.79
		SD	0.99	0.42	0.67	0.67	0.71	
	Q6	M	3.33b	4.42a	3.42b	3.58b	3.69	3.31*
		SD	0.78	0.90	1.08	1.00	1.01	
	Q7	M	3.67	4.25	4.08	4.08	4.02	1.06
		SD	0.65	0.75	1.00	0.90	0.84	
Total		M	4.22	4.47	4.15	4.24	4.27	

* Q: Question, ***p<.001, *p<.05, Duncan test (a > b > c)

The results of expert evaluation on the similarity between real and virtual stretchable tight-fitting garments, For Garment 1, the question which scored the highest in Garment 1 was "Q3. Sleeve length" for the back, while "Q6. Puckering shape" for the back scored the lowest. "Q6. Puckering shape" and "Q7. Fabric appearance" scored in the range of 3 points for the front, back, and side. The mean score of all the questions for Garment 1 was 4.22 points.

For Garment 2, the question which scored the highest in Garment 2 was "Q3. Sleeve length" for the back, while "Q6. Puckering shape" for the back scored the lowest. The mean score of all the questions for Garment 2 was 4.47 points, which was higher than any other garment.

For Garment 3, the question which scored the highest in Garment 3 was "Q3. Sleeve length" for the back, while "Q6. Puckering shape" for the front scored the lowest. The mean score of all the questions for Garment 3 was 4.15 points, which was lower than all other garments.

For Garment 3-1, the question which scored the highest in Garment 3-1 was "Q3. Sleeve length" for the front, "Q1. Overall appearance" for the back, and "Q4. Neckline appearance" for the side, while "Q6. Puckering shape" for the side scored the lowest. The mean score of all the questions for Garment 3-1 was 4.24 points.

According to the results of one-way ANOVA of the mean score of questions for Garment 1, Garment 2, Garment 3, and Garment 3-1, "Q3. Sleeve length" and "Q5. Seam line position and shape" for the front had a significant difference of $p<.001$. The mean score of the two questions scored the lowest in Garment 3. The questions with $p<.05$ were "Q6. Puckering shape" and "Q7. Fabric appearance" for the front and "Q6. Puckering shape" for the side, and the mean score of these questions was the highest in Garment 2 and the lowest in Garment 1. There was no significant difference in other questions.

The results of evaluation by 12 experts about the similarity between real and 3D virtual garments showed that the mean score of all the questions from all the directions was in the order of Garment 2> Garment 3-1> Garment 1> Garment 3. The total mean score of all the questions evaluated for all the garments was at least 4 points, which indicated no big difference between real and 3D virtual garments. Therefore, it can be seen that 3D virtual garments are implemented similarly to real clothes regardless of inserting a lining or a breast cap.

This study analyzed expert opinions on the factors that contributed to a difference in similarity between real and virtual garments. In terms of factors that differ between real and 3D virtual garments in Garment 1, Garment 2, Garment 3, and Garment 3-1 as evaluated by the group of experts, (1) puckering shape and fabric appearance were evaluated as different by 50% of the experts, (2) hem shape and overall appearance by 25%, (3) body or sleeve length by 14%, (4) neckline appearance by 10%, and (5) others by 1% of the experts(Figure 8).

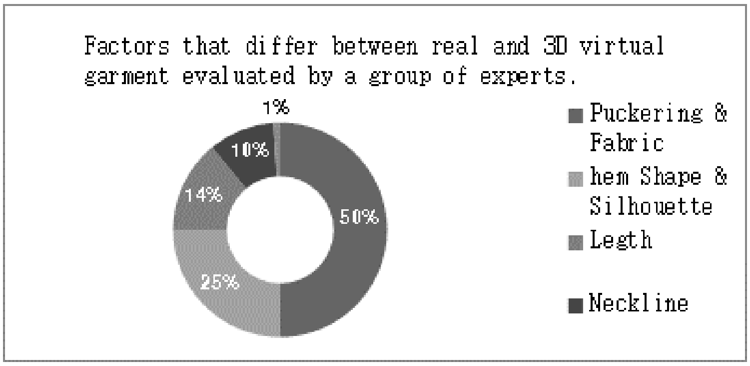


Figure 8. Factors that differ between real and 3D virtual garments evaluated by a group of experts

Conclusion

This study used the virtual clothing software CLO; evaluated the similarity between real and 3D virtual versions of a tight-fitting short-sleeved top without lining (Garment 1), a short-sleeved top with lining (Garment 2), a short-sleeved top with lining and breast cap (Garment 3), and a short-sleeved top with lining on the fitting body fitted with the breast cap (Garment 3-1); analyzed the reasons for the similarity; and compared the similarity between real and virtual stretchable tight-fitting garments.

There are the results. First, for Garment 1, Garment 2, Garment 3, and Garment 3-1, real and virtual garments were photographed in the front, back, and side, and observed by 12 experts to evaluate the similarity between real and virtual garments on a five-point scale. The mean score of all garments was 4.27 points, indicating that the similarity between real and 3D virtual stretchable tight-fitting garments was very high. The one-way ANOVA of the mean score of questions for Garment 1, Garment 2, Garment 3, and Garment 3-1 revealed a significant difference of $p<.001$ in "Q3. Sleeve length" and "Q5. Seam line position and shape" in the front. The two questions had the lowest mean score in Garment 3. Other questions did not show a significant difference of $p<.001$.

Second, the results of expert evaluation on the similarity between real and virtual stretchable tight-fitting garments showed no big difference in the scores of Garment 1, Garment 2, Garment 3, and Garment 3-1. Nonetheless, a comparison of Garment 2, in which breast cap was not inserted, and Garment 3 and Garment 3-1, which used the same Garment 2 but with the breast cap inserted, showed that the mean score of Garment 3 and Garment 3-1 with the breast cap inserted was slightly lower, which suggests that the insertion of the breast cap had a slight effect on the similarity between real and 3D virtual garments.

Third, about expert opinions on factors contributing to differences between real and virtual garments, 50% of the experts cited "puckering and fabric appearance" and 25% said "hem shape and silhouette." About the reason for the difference in puckering and fabric appearance, the experts opined that the real garment was stretched during the clothing and sewing process. In addition, a difference in appearance due to seam allowance was also observed. Some said that while the real garment had seam allowance partly pronounced, the 3D garment had it flat, and puckering shape looked different in the areas where the seam allowance was lumped together, like the sleeve armpit. Furthermore, 14% of the experts said that the 3D virtual garment is shorter than the real garment.

To consider the application of two methods of implementing breast caps, It must be noted that while the method of generating the breast cap as a pattern can modify the pattern size, shape, and physical properties in CLO without any additional cost and computer-generate various types of breast caps, it is more difficult to insert it into the 3D virtual garment. However, although the method of using the fitting body with the breast cap already on is easier, it causes additional costs as it creates the need to have numerous digital fitting bodies-one with the breast cap, one without the breast cap, and different ones for different types of breast caps. In other words, while the two methods provide an equal level of similarity with the real garment, more research is required to identify the method which will allow 3D virtual clothing technology to be used more widely for tight-fitting garments with different types of breast caps.

The experts said that the 3D virtual garment is shorter than the real garment which seems to be because the fabric returns differently depending on fabric elasticity due to a difference in friction between the real fitting body and the 3D fitting body when the garment is stretched to the same point. Furthermore, when the real garment was put on, fabric elasticity or drape differed partly due to the effect of seam allowance and stitch as the garment was stretched. By contrast, the 3D digital garment omitted seam allowance and all fabrics had the same stretchability and drape because tension is set as default, and therefore, there seemed to be a difference in puckering shape and neckline appearance around the seam line.

Likewise, although a virtual garment is represented very similarly to the real one when a real stretchable tight-fitting garment is computer-generated into a virtual one through 3D virtual clothing software, a future study may need to be conducted to figure out how to improve factors found to have contributed to visual difference, such as puckering shape, fabric appearance, length, and neckline appearance.

This study had the limitation that it was not able to analyze how the special sewing technique often used in tight-fitting clothing and different types of sewing threads influenced appearance similarity. A study would need to be conducted to analyze appearance changes in tight-fitting garments across several different types of stitches and further improve the similarity between real and 3D virtual tight-fitting garments. Furthermore, one of the characteristics of tight-fitting garments is that their appearance is modified as the skin is pressed due to pressure from the fabric on the human body. Currently, a 3D soft fitting body has not been fully developed and made available yet, and consequently, this study could not compare the real and virtual garments for this aspect. In the future, it would be necessary to compare and verify various types of clothes for each of the variables in order to expand the use, scope, and reliability of 3D virtual clothing technology. This would make it possible to apply the technology more widely for tight-fitting clothing.

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