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Implementation of Modern Dynamic Approach in Garment Pattern Design for Deaf People

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ABSTRACT

The analysis of the specific needs of the deaf community shows that during the motion of the hands, sign language speaking people require significantly more freedom in their clothing compared to hearing people. Therefore, our topic relates to the development of adaptive clothing with high wearing comfort for sign language speaking people based on the latest technical solutions in the field of clothing design. Typical sign language gestures were scanned with a high-performance MOVE4D scanner, and the data obtained was automatically processed to investigate changes in the sizes of body parts during motion. The resulting dynamic measurements were used to create an ergonomic pattern construction, which was evaluated using virtual modeling. Moreover, based on the newest developed methodology, the impact of style and material parameters on the garment pressure was investigated. After analysis, the optimization of pattern design was carried out on the selected garment piece.

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1. INTRODUCTION

Hearing loss is the fourth highest cause of disability globally. According to the World Health Organisation (WHO), over 5% of the world's population – or 430 million people – require rehabilitation to address their 'disabling' hearing loss (432 million adults and 34 million children). It is estimated that by 2050, over 700 million people – or one in every ten people – will have disabling hearing loss [1]. 'Disabling' hearing loss refers to hearing loss greater than 35 decibels (dB) in the better-hearing ear. The following types of disease are defined:

1) Hearing loss - a person who is not able to hear as well as someone with normal hearing – hearing thresholds of 20 dB or better in both ears;

2) 'Hard of hearing' refers to people with hearing loss ranging from mild to severe;

3) 'Deaf' people mostly have profound hearing loss, which implies very little or no hearing. They often use sign language for communication [2].

We will focus on the last group, as due to the lack of "hearing-speech" communication, this group requires the greatest efforts in terms of social adaptation or rehabilitation.

The word Deaf, with the capital D, is used to refer to a group of people with similar medical conditions, such as hearing loss or deafness. Deaf people tend to communicate in sign language as their first language [3]. Signed languages (also known as sign languages) are languages that use the visual-gestural modality to convey meaning through manual articulations in combination with non-manual elements like the face and body. Similar to spoken languages, signed languages are natural languages governed by a set of linguistic rules [4]. One of the challenging aspects regarding the translation of signed languages compared to spoken languages is that while spoken languages usually have agreed-upon written forms, signed languages do not. Current data from the World Federation of the Deaf suggest there are more than 70 million deaf people worldwide. Totally, they use more than 300 different sign languages.

According to these trends, it is obvious why the deaf community is winning more and more attention in modern society. Many scientists are working in various research fields on problems related to the social adaptation of Deafs.

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Millions of dollars are invested in research related to disease prevention and the development of psychological and social adaptation tools. At the same time, the apparel industry is lowly involved in this trend. The main reason is the widely held belief, that hearing loss people have no special requirements in clothing, as they do not physiologically differ from hearing people. However, there is another reason still presented in our daily lives: it is social discrimination against deaf people, also known as audism. Audism understands the world from a hearing person's perspective and how they face the situations and environments around them. Being a hearing person became a synonym for being normal. This pattern we have in society today results in many people with hearing disabilities being denied of perceiving and affirming themselves as part of the deaf community. This sociocultural construct creates a very hard environment of exclusion, rejection, and invisibility for deaf people [5]. However, both statements caused by external and internal impacts are false or only partially correct.

In the first case, it needed to be taken into account that the preferred method of communication for such people is sign language. Active manual articulation involves stress on the hands, which is significantly increased by using uncomfortable clothing. This consideration is especially true for sign language interpreters. Interpreters from sign language play an essential role in allowing hearing, deaf, and hard-of-hearing people equal access to information and interactions. However, the complexities of the task, the types of visual interpreting, and the enormous range of qualifications brought by the interpreter make it anything but simple. Since the duration of one simultaneous interpretation cycle is up to 4 hours, clothing comfort is of particular importance for this group [6].

As for the tendency to conceal their affiliation with the deaf community, with changing the social acceptance vector towards inclusion, it becomes irrelevant. Deaf organizations, associations, clubs, schools, events, and much more promote social interaction for deaf people. It may play an integral role in boosting one's confidence with interactions that they may have found hard before, or rather find themselves overcoming obstacles that impede them on their path to be treated with equity.

Fashion products for deaf people are coming up as a response to these trends. Some brands offer clothing customization for hard-hearing people through color design or printed information images [7-9]. Another trend is using built-in electronic elements to reinforce sound or simulate acoustic recording [10-11]. At the same time, research on improving the wear comfort of garments for sign language speaking persons was not found in the available sources.

Since using sign language to communicate is the primary functional environment for such people, clothing products in this category must be developed with the optimal ergonomic solution. While also keeping in mind that the product must allow the wearer to perform repetitive movements of relatively constant amplitude for a specific time without any stress to provide the wearer with the necessary comfort. For this reason, clothing for the Deafs should be defined as functional clothing, and an ergonomic approach should be used for its design that accounts for the peculiarities of the functional environment formed by communication in sign language.

Ergonomic considerations dictate that the mechanical characteristics of clothing match the motion, degree of freedom, range of motion and force, and moment of human joints. The working postures, materials handling, movements, workplace layout, safety, and health aspects should be given due consideration while developing the style, cut, and features of a functional garment [12]. For products belonging to functional clothing, these factors are ensured by design (using optimal amounts of constructive additions according to the dynamic effects of the dimensions of the body), constructive elements (vents or folds), and by combining materials with different mechanical properties appropriate to the final purpose of the product.

Since the technological evolution from 3D to 4D scanning systems enabled scanning in motion, significant advances in the development of functional clothing have occurred. The concept of "dynamic body fit" in garment design has evolved significantly. In this case, more attention is paid to determining the typical positions for a particular field of functional activity, on which basis kinematic models for further virtual clothing design are developed [13]. This innovation enables garments to adapt dynamically to body movements under various conditions, enhancing their functionality. Consequently, the widespread adoption of these technologies is a critical factor in accelerating the development cycle and conserving resources within the clothing industry [14].

Moreover, advancements in simulation software have accelerated the movement from 2D to 3D virtual space. The virtual fitting technology includes V-Stitcher by Browzwear (Browzwear Solutions Pte. Ltd, Singapore; 3D Runway from OptiTex, Ltd, Israel; AccuMark 3D from Gerber Technology, Tolland, USA; TUKA3D (Tukatech Inc., USA); Modaris 3D Fit from Lectra Modaris, France; and Vidya from Assyst, Germany. More recently, two other solutions were added with similar capabilities: CLO and Marvelous Designer (CLO Virtual Fashion Inc., Republic of Korea) [15]. Some 3D software programs, like Lectra Modaris, offer the option to fit the garment on an avatar in a static position, with the sole option to lower the arms for a more "relaxed" pose. Others like CLO and Browzwear offer the option to add animations to chosen avatars in simulation mode. These virtual simulation platforms have evolved further, incorporating AI to predict fabric behavior under dynamic conditions with greater accuracy [16]. Such features enable personalized garment adjustments to accommodate diverse body types and movement patterns. The last option is commonly used to improve the ergonomics of the garment. At the same time, a certain evaluation of the designed virtual clothing can also be made through this software [17]. Using 3D virtual simulation can significantly reduce the design process's duration and save on production costs and time.

One especially notable innovation in this field is the use of soft body avatars, which model not only the external shape of the body as a solid object but also consider the internal tissue deformation by simulating clothing-body interaction. These soft avatars provide more accurate predictions of how clothing will behave when the body is in motion, addressing issues that rigid body models cannot, such as the effect of tissue strain and skin elasticity [18].

Overall, these innovations represent a shift from traditional, static garment fitting to a more dynamic, motion-aware design process, promising improvements in both comfort and functionality, particularly for specialized garments like those for individuals who rely on sign language communication or those requiring adaptive clothing solutions. Therefore, our topic relates to improving the ergonomics of a formal jacket for sign language speakers by integrating data on human body dynamics obtained through 4D scanning for further use in virtual clothing design.

In this context, tools like CLO have become indispensable in ergonomic research. So, in the paper [13], the authors propose an ergonomic and personalized approach for designing the patterns for a men's jacket model with a fitted silhouette (business casual outfit) using digital tools while integrating data regarding the dynamics of the human body to improve functionality and comfort. They use CLO to analyze the balance and fit of the product on the avatar in static and dynamic positions to determine how well the product fit on the different parts of the body, whether the constructive, stylistic details of the model were preserved, and whether there were areas of the product with possible constructive defects. The study [19] aimed to improve garment pattern design for cycling sports from the aspect of clothing pressure to provide support and enhance comfort to the user. This paper investigated the suitability of pressure maps from 3D fashion design software CLO for design. Moreover, the impact of the mechanical properties of fabric was analyzed. In particular, the virtual prototyping tool CLO and pressure mapping were employed to achieve the required compression while ensuring fit and comfort in static and dynamic cycling positions. The impact of fabric types on garment fit has been shown by generating the stress, strain, and pressure maps with a virtual simulation. The output was found to be sufficiently accurate to optimize the garments based on material and cycling posture [19].

Although research and development of virtual fitting systems have attracted a large number of researchers, the key technologies for virtual fit evaluation still need to be mature, and some problems still need to be solved or remain undeveloped. For example, a clear protocol for garment fit testing of the 3D simulation programs must be established. However, they offer a comprehensive set of tools for checking the digital fit. These tools allow us to analyze the structural changes of the textile through the material parameters and impact of the avatar. So far, the evaluation of clothing fit and its characteristics is performed visually [13, 19]. Quantitative assessment is only possible at certain predetermined points and not over the entire surface of the product [20-22]. Both ways do not provide the necessary accuracy and reproducibility of research and do not allow the use of these data for analysis and prognosis.

With these aspects in mind, this study aims to improve the ergonomics of a formal jacket for people who use sign language in everyday life by matching the motion with the mechanical characteristics of clothing and using a new approach to clothing fit assessment in virtual simulation systems.

2. MATERIAL AND METHOD

2.1 Material

Since the objectives of this work involve the creation of formal clothing for people who use sign language, including sign language interpreters, we have chosen outerwear fabric from a linen\cotton blend because it has a high level of hygroscopicity and thermal conductivity, which makes this textile very comfortable for active articulation, typical for sign language speakers. Virtual fabric prototypes from the CLO database were used to simulate the designed product. However, the real values of the mechanical properties of fabric determined by standard testing instruments cannot be uploaded directly to the CLO simulation software library. The software automatically provides relative values of the fabric's mechanical properties for the fabric chosen. The selected materials are characterized by the following properties:

Construction		Woven
Composition		55 Linen, 45 Cotton
Weight		186 g/m^2
Thickness		0,4 mm
Stretch[2]	weft	58
	warp	59
Bending[1]	weft	47
	warp	53

2.2 Method

Study of the typical movements of sign language

Since the main objective of our research was to develop an ergonomic construction, it was essential to study the product's behavior on the body shape during movement. In this case, the movements should correspond to the typical ones for the investigated functional environment.

[2] The fabric's tensile properties do not follow existing standards. They were obtained through a testing instrument composed as part of the software for creating a digital fabric library in CLO software. The units of measurement are virtual units (v.u.). According to the CLO manual, to refer to the fabric elasticity, the term "stretch" will be used in further discussion.

Modern high-speed 4D scanning technology is used to analyze typical motions and develop virtual prototypes. The scanning is performed with the MOVE4D scanner, installed in the scan lab of the Chair of Development and Assembly of Textile Products, ITM, TU Dresden, Germany. The scanner consists of 12 scanning modules, which can record motion with a special resolution of up to 1 mm and up to 180 frames per second.

MOVE4D software automatically generates homologous meshes during the processing of scanned data. All approximate 50k vertices move with the body between the frames while remaining associated with the same body parts. This means these vertices can be considered as landmarks and used to analyze the motion. This special feature is used in the current work.

After scanning and processing the data, an extensive list of files with the body geometry, associated textures, and light data is available. To simplify the data processing, at the Institute of Textile Machinery and High-Performance Material of the TU Dresden was developed a Matlab workflow to automatically estimate the distances between selected points within each frame based on the mesh vertex IDs data. Using this program, we calculated the changes in the distances of the body surface measurements during selected typical movements.

Development of the basic pattern design

The basic pattern design of a women's jacket for a typical female figure was developed in Graphis CAD. Graphis CAD is a reputed system for parametric garment design. The pattern construction can be created in two ways: using integrated interactive modules or by computational and graphical generating. The construction is based on a flexible system of measurements, and the design process is recorded in the form of an algorithm. An additional advantage is automatic grading. These capabilities of Graphis CAD allow us to quickly adapt finished constructions to new requirements while ensuring high fit quality.

Virtual simulation of the product and fit quality assessment

The developed basic pattern construction was imported into the virtual simulation program CLO. The process of simulating a garment in CLO involves the virtual stitching of parts and their placement on a virtual mannequin. The software's functionality allows for the assessment of the quality of the product's fit not only visually but also based on the specially developed tools. CLO offers three different tools for analysis: the Stress Map, the Strain Map, the Pressure Points Map, and the Fit Map (Table 1). These maps are calculated within the simulation and displayed in a color gradient over a specific range. The Stress Map calculates the deformation of the textile by external influences. The Strain Map indicates the stretching of the textile. The Pressure Points show where the textile directly interacts with the avatar's surface. The Fit Map calculates the three previous values and indicates where the clothing fits tightly or cannot be worn at all.

Picture clustering and color extraction

We utilized the Image Color Analysis Tool, an open-source Matlab Add-On [23], to perform image clustering and color extraction. This tool facilitates color-based segmentation using k-means clustering, a widely used algorithm for partitioning data into distinct groups. K-means clustering operates by treating each object (in this case, a pixel) as a point in a multidimensional space. It identifies clusters such that points within the same cluster are as close to each other as possible while being as distant as possible from points in other clusters. For our analysis, clustering was performed in the RGB color space to extract relevant image regions and evaluate segmentation results. The developed workflow consists of the following steps:

⇒ Read and Display the Image: Load the selected image into Matlab. Display the image to visualize the input data before clustering.

⇒ Cluster the Image Using K-Means: Perform k-means clustering in the RGB color space. Display the clustered image to confirm the segmentation results.

Table1. Garment Fit Maps in the 3D window to check 3D Gament's fit*

Stress Map	External stress causes garment distortion per area of the fabric, which appears in a range of colors and numbers. The Stress Map appears in eight colors: red indicates the strongest stress (100kPa), while blue indicates zero distortion (0.00kPa). Other numbers in between are expressed as the gradation of two colors.
Strain Map	The garment's distortion rate due to external stress appears in percentage. The Stain Map appears in eight colors: red indicates 120% of the distortion rate, while blue indicates 100% (no distortion). Numbers in between are expressed as the gradation of two colors.
Fit Map	Fip Map shows the tightness of the 3D garment. Can't Wear appears in red, indicating not wearable area. Very Tight appears in orange, indicating a very tight area. Tight appears in yellow, indicating a slightly tight area. Show Pressure Points Show or hide contact points between 3D Garment and Avatar.

*[Garment Fit Maps Copyright © 2023 CLO Virtual Fashion LLC. All Rights Reserved. https://support.clo3d.com/hc/en-us/articles/360000436368-Garment-Fit-Maps]

⇒ Segment Image by Color: Create separate images for each identified color segment. This step isolates specific regions in the image based on their cluster assignment.

⇒ Quantify Color Distribution: Compute the number of pixels belonging to each color cluster and calculate the percentage of the image occupied by each color, providing quantitative data for further analysis.

⇒ Generate a Histogram: Plot a histogram to visualize the distribution of colors within the image, offering a clear representation of the clustering results.

3. RESULTS AND DISCUSSION

Ensuring the dynamic fit of clothing is based on the study of movements that are typical for a given functional environment. In our case, the task relates to the study and classification of sign language movements in order to take them into account when providing dynamic compliance. For this purpose, an interpreter with 30 years of experience in sign language communication and sign language interpreting was also consulted. In addition, methodological guidance for sign language interpreters was examined, and several videos with sign language transcription were watched. On this basis, the typical shoulder and forearm movements were determined, representing the basis for most of the signs. A kinematic model from modern biomechanics was used to schematically represent and record the results.

In modern biomechanics, the human body is viewed as a cinematic chain in which each limb has its numbering and can perform three types of movement, which can be recorded in vector or coordinate form [24]. Using the methodology described below, typified patterns of basic sign language movements were developed to be utilized in subsequent research phases.

To simulate real usage conditions, we captured typical sign language movements using a 4D scanner. The scanning and data processing procedures are detailed in [25]. To extract the data necessary for the pattern design stage—namely, the dynamic measurements of the human body—a custom script was developed in MathWorks' Matlab programming environment. This script enabled the extraction of key measurements based on the scan data of the human body surface in motion in the following way. For analyzing the lengths of the selected measurements (listed in Table 2), the relevant curves were defined and saved as a list of vertex indices IDs. Figure 1a illustrates the identified curves and their associated vertices IDs. Once the motion data was captured, the script processed multiple frames from the motion sequence (Figure 1b). Discrete curves for each selected frame were plotted, and their length were computed. Figure 1c demonstrates the computed length of the curves across frames, highlighting the variations in body dimensions during movement. The workflow for this processing in detail and open issues were reported in [26].

This methodology allowed us to extract particular frames from the obtained dataset that are critical for providing ergonomics during sign language communication, further called extreme postures. For the extreme posture, we defined in the previous step, the values of the maximum dynamic effect of body dimensions affecting the pattern construction were determined. Table 2 provides a summary of the key measurements in static and dynamic states, based on which the absolute and relative dynamic effect was calculated.

The measurements shown in Table 2 were determined on a sample of a female size 36 according to the European size system. These measurements were taken for each separate captured frame during the scanning of a series of sign language movements. After that, the data was statistically analyzed. The values of the following statistical parameters were determined by the confidence level of 95.0%: mean value, standard error, median, mode, standard deviation, minimum, and maximum. The maximum value from the entire series of captured frames was adopted as the body dimension in dynamic.

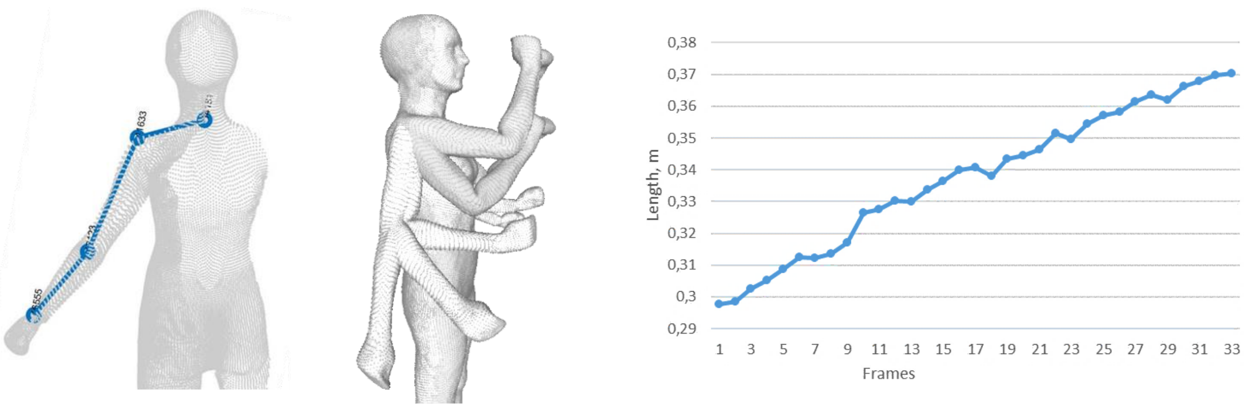

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Figure 1. Change the position and length of selected segments in motion:
(a) Matlab visualization of the distances selected for measurement; (b) sign language movement in separate frames;
(c) Matlab plot of the length of the particular body segment during the selected motion

Table 2. Calculation of measurements for deaf people's clothing design

Measurement	Body dimension in static, mm	Body dimension in dynamic, mm	Dynamic effect absolute, mm	Dynamic effect relative, %
7CV to waist	396	415	19	5
Arm length	519	567	48	9
Arm girth	239	255	16	7
Back armpits	300	374	74	25
Front armpits	287	242	-45	15

The analysis revealed significant variations between static and dynamic body dimensions, as shown in Table 2. The arm length showed a dynamic increase of 48 mm (9%), indicating substantial extension during signing motions. The arm girth expanded by 16 mm (7%), demonstrating increased muscular activity and movement in this region. The back width measurement exhibited the most pronounced dynamic effect, with a 74 mm (25%) increase, highlighting the significant strain and movement in the upper back during active gestures. Conversely, the front armpits showed a relative decrease of 45 mm (15%), suggesting compression or forward movement in this area. Furthermore, the 7CV to waist measurement increased by 19 mm (5%), which, although smaller in magnitude, is critical for ensuring sufficient flexibility in the torso region during dynamic movements. These dynamic effects underscore the necessity of designing garments with appropriate allowances in areas experiencing significant dimensional changes, such as the arms and upper back, while considering compression zones like the front armpits.

At the next stage of our research, the basic pattern construction of the women's formal jacket was developed. Since the ergonomic approach involves the integration of dynamic measurement into the design parameters, it was necessary to develop a flexible system. The necessary flexibility became possible due to the advantages of GRAFIS software. The main constructive ease allowances in the construction process were set in the form of variable values (X-Werte). Varying these values made it possible to track how the configuration and arrangement of certain parts of the construction changes while adapting to a particular sign language movement.

Most of the parametric changes concern the width of the back and front parts, the width and length of the sleeves, and the dimensions of the dart, which causes further deformations of the armhole and the sleeve cap (Figure 2). It is obvious that ensuring ergonomics in a constructive way will lead to a complete deformation of the product shape and cause plenty of fit defects in the product. This option is unacceptable, as the jacket is a formal casual garment supposed to have a good appearance in static positions and retain it during typical movements.

The virtual prototyping process covers several work steps, starting with a 2D pattern preparation and ending with the development of a final virtual prototype. To simulate the product, the details of a women's jacket designed in Graphis CAD with typical for this product range ease allowances were imported into the 2D area of the CLO software and assembled. The linen/cotton fabric from the virtual CLO database was selected as the top fabric, and then the properties were adjusted and processed (Table 1). Once the virtual garment has been assembled and placed roughly on the avatar, the real process is simulated using the CLO tools in the avatar window. Analysis of garment fitting was done through optical assessment, stress, and fit maps, which were created during the simulation process for the garment prototype.

The simulation was conducted under both static and dynamic conditions. To develop our methodology, we selected the dominant hand position commonly used in sign language communication—specifically, where the arms are raised to shoulder level and bent at the elbows. Figure 3a depicts the simulation of the jacket based on the relevant material properties. Notably, significant material deformation is observed in the shoulder and elbow regions, characterized by pronounced tensile folds. This observation is confirmed by the Stress Map evaluated for the specified conditions (Figure 3b), which visualizes external stresses caused by garment pressure through a color-coded representation. Regions of higher stress, indicated by red hues, are concentrated in the mid-back and elbow areas.

It is evident that moving the hands forward or upward requires substantial effort due to increased strain, which, as previously noted, may lead to rapid fatigue. Therefore, it is essential to adapt the garment's pattern design to suit these usage conditions.

Attempting to address this issue using traditional methods—such as accommodating freedom of movement through dynamic ease allowances—often results in undesirable fit defects. Figure 3c illustrates the fit disruption, characterized by folds on the garment's surface, that occurs when the back width ease is increased to accommodate the dynamic effects identified in previous motion studies. This underscores the need for a balanced approach that integrates material properties with optimized pattern parameters.

To determine the conditions for achieving this compromise, we designed a multifactorial experiment, varying both material stretch and pattern ease allowance parameters. The jacket was simulated multiple times, adjusting the fabric "stretch" within a range of 40 to 70 virtual units in increments of ±10, and varying the back width ease from 5 to 45 mm in 10 mm steps. The Stress Map for each simulation was captured using the built-in SnapShot function.

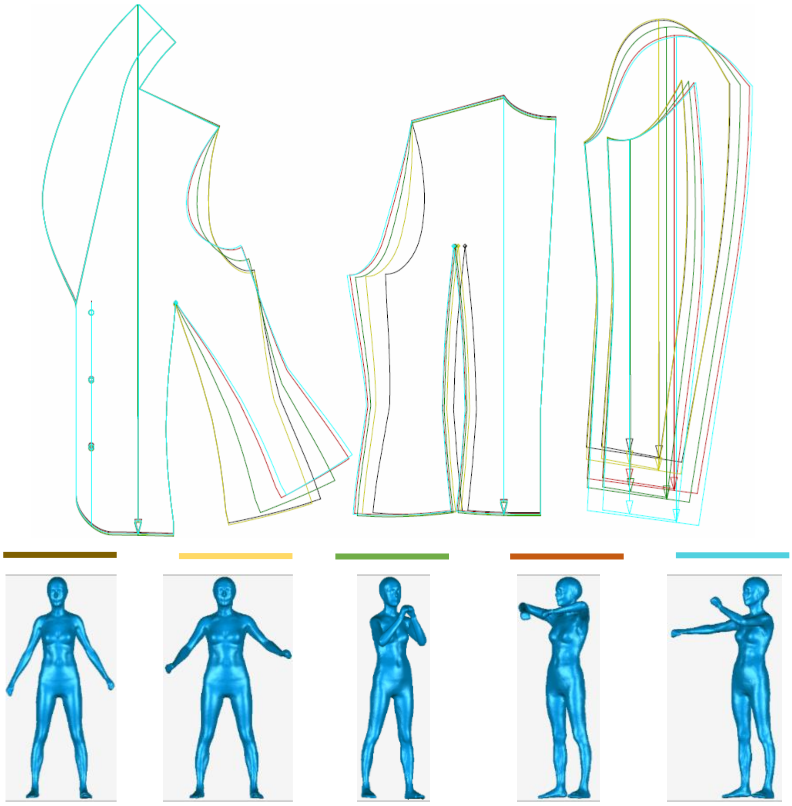

Figure 2. Comparative analysis of the motion-oriented design geometry

Therefore, it was decided to use another approach, which involves compensating for dynamic growth by combining the ease allowances and elasticity of the material. For this purpose, it was necessary to investigate the impact of these factors on the ergonomics of the pattern design and the quality of the product's fit. The research was performed according to the following workflow:

- ⇒ Importing 2D flat pattern
- ⇒ Fabric properties adjustment
- ⇒ Importing 3D human body model in a motion corresponded to critical sign language postures
- ⇒ Arrangement and simulation of the product in CLO
- ⇒ Stress Map recording while varying the ease allowances and fabric elasticity
- ⇒ Picture cluster generation based on the obtained images
- ⇒ Color extraction and plotting graphs
- ⇒ Calculating and graphical analysis of the data obtained
- ⇒ Optimum determination for the studied variables
- ⇒ Validation of the results

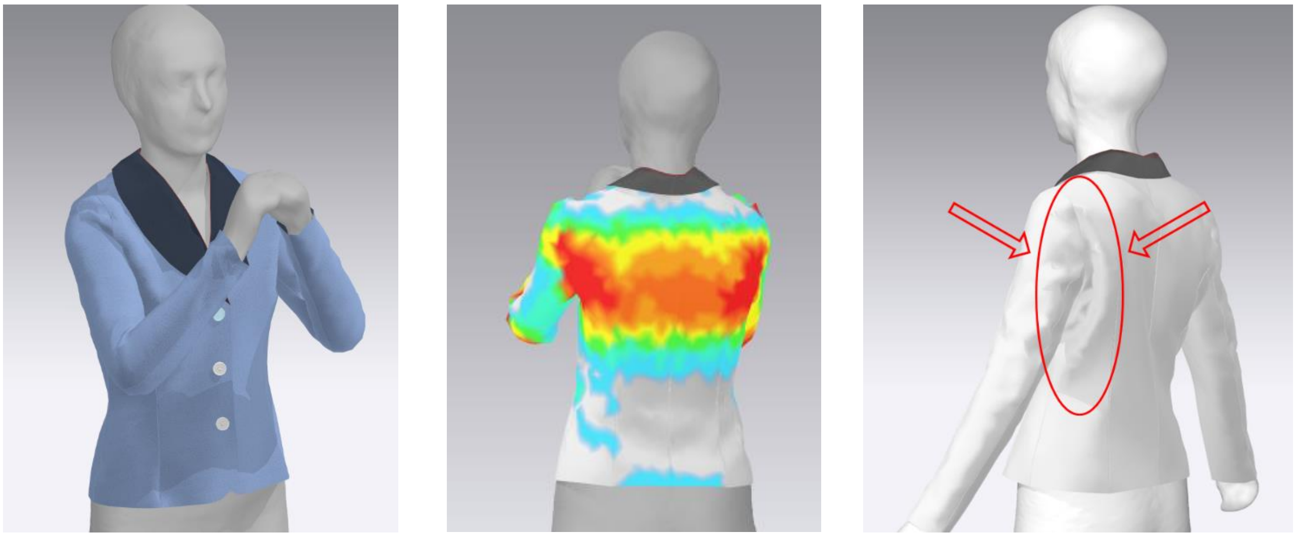

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Figure 3. Dynamic fit analysis through virtual simulation:
(a) CLO jacket simulation; (b) Stress Map; (c) example of fit defects caused by dynamic ease

The images generated in CLO were stored as graphic files to document stress distribution across the garment. However, to analyze the interaction between the studied factors quantitatively, these images required further processing. To transfer the graphics into numerical data, the technical solution was proposed and realized in the following steps. The original CLO snapshot (Figure 4a) was imported into Matlab. Background colors unrelated to the stress evaluation scale were removed to isolate relevant stress data. These regions were converted to black (Figure 4b) and treated as a non-relevant background in the subsequent clustering step. Matlab's in-built clustering tool was used to segment the image based on its color palette (Figure 4c). This process categorized the Stress Map colors into meaningful groups corresponding to the stress levels in the garment. A histogram (Figure 4d) was generated, displaying the percentage of each color identified in the processed image. This histogram provided a clear numerical representation of stress distribution across the garment.

Using the Matlab software environment, the stored images were clustered to identify and quantify the main colors represented in the Stress Map. These correspond to the pressure level colors exerted on the garment, as defined by the CLO simulation. Matlab's image processing capabilities allowed for extracting and plotting numerical data, specifically the percentage distribution of each identified color within the image. The complete workflow is illustrated in Figure 4.

The identified color palette was divided into two groups to analyze pressure effects:

⇒ High-Pressure Group: This included colors in the red and yellow spectrum, representing stress values between 58 and 100 kPa. These areas indicated unacceptable pressure, which could negatively affect the garment's ergonomics and comfort.

⇒ Low-Pressure Group: This is comprised of colors in the green and blue spectrum, representing stress values between 0 and 58 kPa. These areas were deemed acceptable, as they did not significantly impact the garment's ergonomic performance.

The graphical analysis (Figure 5) demonstrated the relationship between material strechability (Stretch) and back width ease on stress values. As we can see, the percentage of red colors rises rapidly with increasing "stretch"-properties of the materials, especially in the range from 50 to 60 v.u. Most suit fabrics belong to this "stretch" range. At the same time, the growth trend in the red color ratio with increasing ease allowances values is much less. This indicates that the most effective way to ensure ergonomics in the pattern design is to use elastic materials. An increase in the value of the ease allowances leads to the occurrence of fit defects and has a much smaller impact on the high-pressure area in the garment. Thus, by varying the amount of eases and selecting materials with appropriate elasticity properties, the existing conflict between ergonomic design and a good fit can be resolved.

This methodology provides a clear, logical progression from image acquisition to quantitative analysis, ensuring the postprocessing of the numeric data according to the chosen purpose. By integrating the obtained results into the design process of fitted fashionable garments, the resulting garment product will better meet the customer's requirements and significantly increase their confidence and satisfaction.

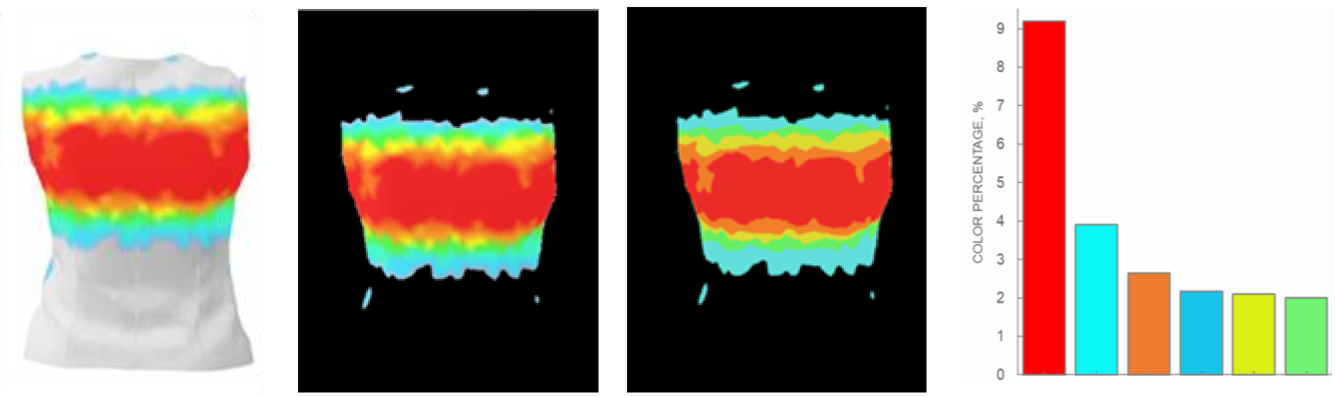

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Figure 4. Color analysis for the Stress Map image using Matlab app:
(a) CLO snapshot image; (b) original image after removing the background colors; (c) clustering; (d) Matlab color histogram

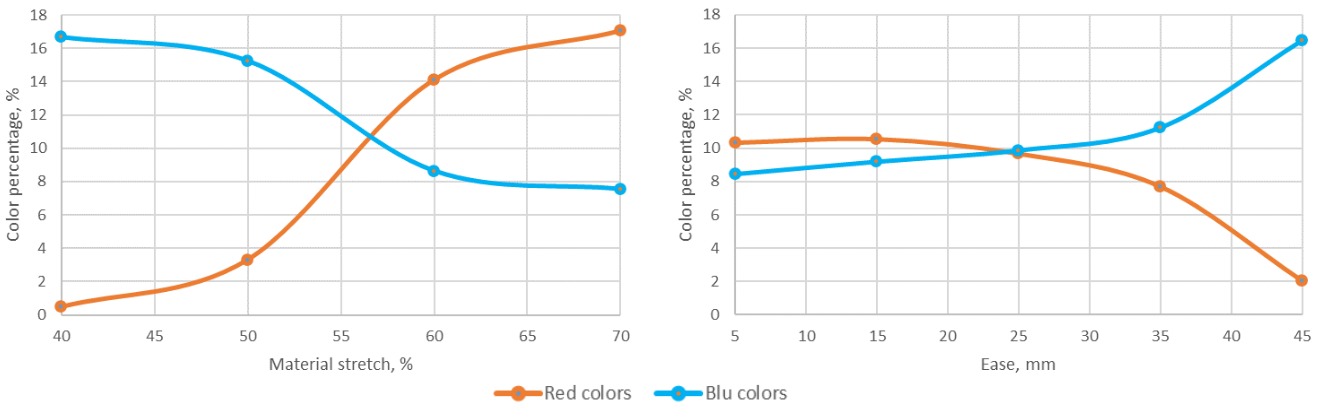

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Figure 5. Graphs of the impact of material elasticity (Stretch) (a) and the back width ease (b) on the stress value

4. CONCLUSION

An essential aspect of the ergonomic design of functional clothing is to consider the typical movements of the usage environment. In the case of deaf people, these are movements of sign language. Modern scanning and data processing methods made it possible to obtain detailed information about the kinetics of the studied sign language movements and create virtual animated prototypes for further export to virtual 3D clothing design systems. By integrating dynamic data into the design process of fitted fashionable garments, the resulting garment product will better meet the customer's freedom of movement and increase their well-being.

Changes in the shape of body parts during communication in sign language, which significantly affect the parameters of clothing design, have been studied. Based on the obtained dynamic measurements, an ergonomic pattern construction was created. It was shown that ensuring ergonomics by dynamic measurement will lead to a complete distortion of the product shape and cause plenty of fitting defects. This option is unacceptable, as the jacket is a formal casual garment supposed to have a good appearance in static positions and retain it during typical movements. Therefore, a new procedure has been proposed to ensure that ergonomics is combined with a good fit.

The 3D visualization of the model on the animated avatar enabled the identification of design solutions based on the ergonomic criteria of functional clothing models. The ability to visualize the level of pressure provided useful information for the optimization of material and style parameters while considering the requirements for wearing comfort. Since the problematic point of all previous studies was the quantitative assessment of Garment Fit Maps in CLO, we proposed a methodology for solving this issue by applying color extraction. Based on the developed methodology, the impact of ease allowances and material elasticity on garment pressure was investigated. The resulting data were used to develop recommendations for designing an ergonomic construction with a good fit for people who communicate in sign language. The developed approach can be scaled to other functional clothing ranges.

Future research will deal with sleeve parameters because the sleeves have the second largest areas of high garment pressure after the back part caused by the design's non-compliance with ergonomic requirements. The next step will be the automation of the developed approach, which will help reduce the time required for data processing and analysis. Of course, the selected clothing range is a multilayered construction, and the presence of additional layers may change the results obtained.

The presented study can be applied for future analyses and operational validations regarding the optimal values for ease allowances, multilayered structures typical for a jacket, and other types of materials. The results provided a theoretical basis and practical guidance for clothing designers and engineers involved in functional clothing design and assisted in evaluating the garment fit while using a virtual simulation system.

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DISCLOSURE STATEMENTS

The research results reported in this publication were presented at the International Izmir Textile and Apparel Symposium IITAS 2023 in Izmir, Turkey. The method used in the present study as part of the research methodology to evaluate movement comfort was presented at the Premier Multidisciplinary International Conference and Exhibition on 3D Human Body Scanning and Processing Technologies 3DBODY.TECH 2022 in Lugano, Switzerland .

REFERENCES

1. World Health Organization. (2023, February 27). Deafness and hearing loss. Retrieved from https://www.who.int/news-room/fact-sheets/detail/deafness-and-hearing-loss

2. University of Washington. (2022, May 5). How are the terms deaf, deafened, hard of hearing, and hearing impaired typically used? Retrieved from https://www.washington.edu/doit/how-are-terms-deaf-deafened-hard-hearing-and-hearing-impaired-typically-used

3. Foggetti, F. (2023, March 23). The Deaf Community: What it is, characteristics and who is part of it. Retrieved from https://www.handtalk.me/en/blog/deaf-community/

4. Sandler, W., & Lillo-Martin, D. (2006). Sign language and linguistic universals. Cambridge: Cambridge University Press.

5. Gala, A. S. (2022, July 28). Audism and the discrimination against deaf people. Retrieved from https://www.handtalk.me/en/blog/audism/

6. Adam, R., Aro, M., Druetta, J. C., Dunne, S., & Af Klintberg, J. (2014). Deaf interpreters: An introduction. *Deaf Interpreters at Work: International Insights*, 1, 18.

7. Deaf Apparel. (n.d.). Retrieved from https://www.deafapparel.com

8. Deaf Clothing. (n.d.). Retrieved from https://deafclothing.com

9. Parfitt, E. (2019, October 21). Introducing a new fashion brand: DEAF IDENTITY. Retrieved from https://www.hearinglikeme.com/introducing-a-new-fashion-brand-deaf-identity

10. Caderas, U. (2020, September 7). Vibrating suit allows deaf people to 'feel' music. CNN. Retrieved from https://edition.cnn.com/style/article/chase-burton-vibrating-suit-spc-intl/index.html

11. Maiorana-Basas, M., & Pagliaro, C. M. (2014). Technology use among adults who are deaf and hard of hearing: A national survey. *The Journal of Deaf Studies and Deaf Education*, 19(3), 400–410. https://doi.org/10.1093/deafed/enu005

12. Gupta, D. (2011). Design and engineering of functional clothing. *Indian Journal of Fibre and Textile Research*, 36, 327-335.

13. Avadanei, M. L., Olaru, S., Dulgheriu, I., Ionesi, S. D., Loghin, E. C., & Ionescu, I. A. (2022). New approach to dynamic anthropometry for the ergonomic design of a fashionable personalised garment. *Sustainability*, 14, 7602. https://doi.org/10.3390/su14137602

14. Klepser, A., & Morlock, S. (2020). 4D scanning - Dynamic view on body measurements. *Communications in Development and Assembling of Textile Products*, 1(1), 30-38. https://doi.org/10.25367/cdatp.2020.1.p30-38

15. Chaudhary, S., Kumar, P., & Johri, P. (2020). Maximizing performance of apparel manufacturing industry through CAD adoption. *International Journal of Engineering Business Management*, 12. https://doi.org/10.1177/1847979020975528

16. Wang, Z., Tao, X., Zeng, X., Xing, Y., Xu, Z., & Bruniaux, P. (2023). A machine learning-enhanced 3D reverse design approach to personalized garments in pursuit of sustainability. *Sustainability*, 15(7), 6235. https://doi.org/10.3390/su15076235

17. Wang, Y.-X., & Liu, Z.-D. (2020). Virtual clothing display platform based on CLO3D and evaluation of fit. *Journal of Fiber Bioengineering and Informatics*, 13(1), 37-49. https://doi.org/10.3993/jfbim00338

18. Schmidt, A.-M., & Kyosev, Y. (2023). Finite element modeling of textile-soft material interaction using 3D/4D scan data. In Proceedings of the 14th European LS-DYNA Conference, Baden-Baden, Germany.

19. Teyeme, Y., Malengier, B., Tesfaye, T., Vasile, S., & Van Langenhove, L. (2023). Fit and pressure comfort evaluation on a virtual prototype of a tight-fit cycling shirt. *Autex Research Journal*, 23. https://doi.org/10.2478/aut-2021-0057

20. Wu, R., & Liu, Z. (2022). Research on improving garment fit through CLO 3D modeling. In Proceedings of the International Seminar on Computer Science and Engineering Technology (SCSET) (pp. 204-207), Indianapolis, IN, USA. https://doi.org/10.1109/SCSET55041.2022.00055

21. Huang, S., & Huang, L. (2022). CLO 3D-based 3D virtual fitting technology of down jacket and simulation research on dynamic effect of cloth. *Wireless Communications and Mobile Computing*, 2022, Article ID 5835026, 11 pages. https://doi.org/10.1155/2022/5835026

22. Liu, W., Yao, T., Yao, C., & Liu, P. (2021). Research on pressure comfort of yoga suit and optimization scheme of pattern based on CLO 3D software. *Journal of Physics: Conference Series*, 1790, 012016. https://doi.org/10.1088/1742-6596/1790/1/012016

23. Dorad. (2024). Image Color Analysis Tool. MATLAB Central File Exchange. Retrieved from https://www.mathworks.com/matlabcentral/fileexchange/75116-image-color-analysis-tool

24. Roupa, I., da Silva, M. R., Marques, F., et al. (2022). On the modeling of biomechanical systems for human movement analysis: A narrative review. *Archives of Computational Methods in Engineering*, 29, 4915–4958. https://doi.org/10.1007/s11831-022-09757-0

25. Sadretdinova, N., & Kyosev, Y. (2022). Method for evaluation of the motion comfort of the clothing for deaf people using high-speed (4D) scanning. In Proceedings of 3DBODY.TECH 2022 - 13th International Conference and Exhibition on 3D Body Scanning and Processing Technologies, Lugano, Switzerland. https://doi.org/10.15221/22.60

26. Kyosev, Y., et al. (2022). Method for automatic analysis of the clothing-related body dimension changes during motion using high-speed (4D) body scanning. In Proceedings of 3DBODY.TECH 2022 - 13th International Conference and Exhibition on 3D Body Scanning and Processing Technologies, Lugano, Switzerland. https://doi.org/10.15221/22.24