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Curvature change of moving bodies and its application for development of protective elements for protective clothing

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ABSTRACT

When the human body moves, the body curvatures always change on the corresponding parts of the body. For ideal protective clothing, body curvatures during different movements have to be taken into account, as they influence the protection and the wearing comfort. For this reason, this study will focus on demonstrating methods to visually display such curvature changes. The changes are visually shown in different poses. The aim is to use this method to optimize protective elements on body parts with increased curvature changes. This would make protective clothing safer and more comfortable to wear.

Keywords
Curvature
protective clothing
safety
comfort
body movement

1 Introduction

Personal protective equipment is becoming increasingly important in today's world. Protective equipment is designed to minimize risks and protect against serious injury to people. In the field of police, different equipment is used: underwear vests, ballistic vests and stab protective vests. Such equipment is also increasingly used in other fields, such as bodyguards, doorkeepers, etc. [1]. There are two basic variants of today's personal protective equipment. One variant consists of hard and the other of a soft protective surface. The hard one consists mostly of inflexible and rigid solid bodies such as metal or ceramics and the soft one of many overlapping textiles [2,3].

The necessary stab protection of protective clothing can be adjusted by a suitable combination and matching properties of fiber material, surface construction, design and finish. The multi-layer textile surface structures primarily used in stab-resistant west serve to absorb the energy of a puncture or, ideally, to prevent it altogether [4-7]. Kevlar fabrics are often used for stab-protective clothing. But also nonwovens made of high-strength fibers (*para*-aramid or polyethylene) are used. The fibers have excellent potential for use in stab protective clothing due to their flexibility, low weight, good mechanical and chemical properties, which can be actively adapted to the respective area of application (different protection classes) [8].

New approaches are being investigated for minimizing weight and increasing wearer comfort while maintaining the same level of protection. One innovative method could be the additive manufacturing of protective geometries printed directly onto a textile substrate. Additive printing has become increasingly popular in recent years due to the high level of design freedom it offers [9]. This freedom also offers new opportunities for the development of interlocking protective geometries in the field of personal protective equipment. By subdividing today's mostly solid large-area protective surfaces, additively manufactured protective geometries are to be used for personal protection in the future. Nature serves as a reference for this purpose. Animals that protect themselves against enemies with protective armor or scales, such as fish, alligators, or armadillos [10,11]. Figure 1 shows a design example of a scale structure that could serve as protective armor. These bio-inspired geometries can provide better mobility of the protective clothing in the future [2,12]. However, this requires a detailed understanding of how such protective geometries behave during movement. If the protective geometries are pulled too far apart during movements, unprotected areas can result. The detection and optimization of the protected area in relation to the total area must also be taken into account [13]. To be considered in the additive manufacturing of such protective geometries as shown in Fig. 1 is the planar print, but the subsequent non-planar (biaxial curvature) wear on the body [14,15].

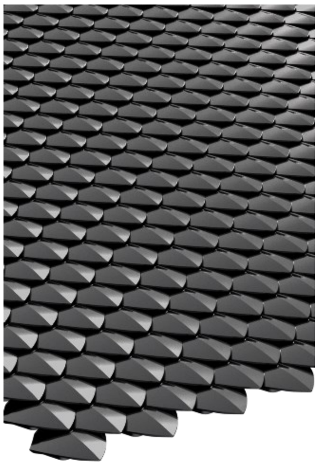

Fig. 1 Design draft of a bio-inspired geometry as protective armor.

When the human body moves, the body curvatures always change at the corresponding body regions. For ideal protective clothing, the body curvatures during different movements must be taken into account. Movements influence the protection and the wearing comfort. For this reason, this study focuses on demonstrating methods for visually representing such curvature changes. The changes are visually represented in different poses. The aim is to demonstrate this method for optimizing protective elements on body parts with increased curvature changes.

2 Method

For the visualization of movements the software *Blender* (version 3.3.1.) was used by *The Blender non provide Foundation*. Blender is a free and open source 3D development tool. It supports the entire 3D workflow from modeling, rigging, animation, simulation, rendering, compositing to motion tracking. Blender can be used for video editing and also for game creation [16]. For the rigging an avatar from *Mixamo* was used, which is part of the *Adobe Family* [17].

The program *MeshLab* was used for the curve analysis. Meshlab is a free open-source system for processing and editing 3D triangle meshes. It provides a set of tools and utilities for editing, cleaning, repairing, checking, rendering, texturing and converting meshes, using different file types. It also offers other functions for processing raw data [18].

In a first step, a protective surface was define on an avatar with Blender. It consists of the front part, the back part and the shoulder protectors, which are shown in Fig. 2 with contour lines in red. Then, UV unwrapping of the marked parts is carried out in Blender. UV unwrapping is a translation of a three-dimensional surface into the two-dimensional coordinate system of a flat bitmap image [19]. Unwrapping is needed to project a UV grid image onto the individual areas. The UV grid consists of light and dark squares with a colored marker within the squares. The grid is later used to represent distortions during movement.

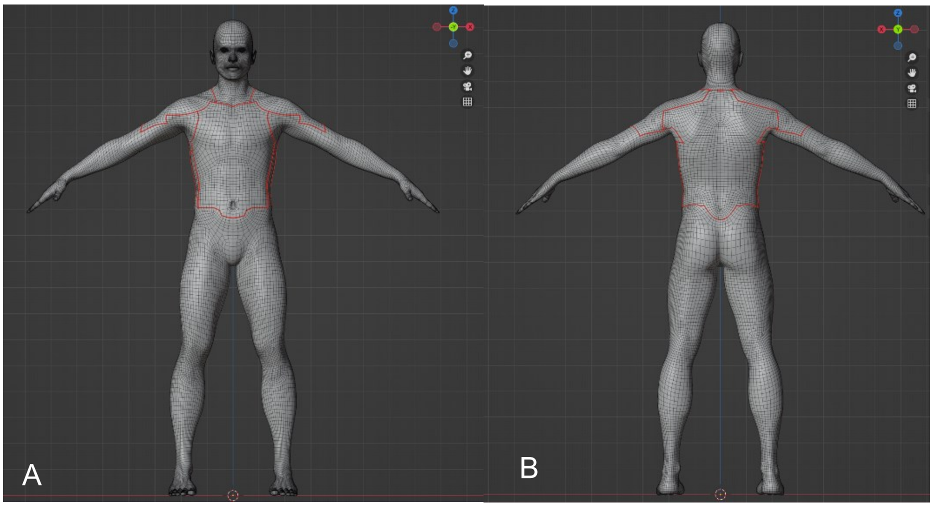

Fig. 2 Front and back view of an avatar with individual protective surfaces drawn in red.

For visual viewing and rendering, Blender needs further information, such as light source, camera settings, avatar with motion sequence. Figure 3 shows the overall setup in Blender. The avatar is in a neutral position with corresponding rigs and the corresponding bones to be controlled. Skeletal animation or also rigging is a technique for presenting a 3D character model using a series of interconnected digital bones [20]. To improve the visualization, the rig with the virtual bones of the respective movement was placed next to the avatar, while the virtual bones are nevertheless linked to the avatar. To visualize different movements, the movement “Split Reaction”, pulling a weapon (motion 1) and “Upwards Thrust” a defensive pose (motion 2) from Mixamo were used (left and right beside the avatar in Fig. 3). To record the movement, a camera perspective was used that moves along with the movement and focuses on the right shoulder. A light source (sun) was added to improve the lighting conditions and for rendering. In this study, the avatar is assigned two movement sequences. However, it is possible to move the individual bones and bone groups manually and to define movements independently. Further movement sequences can be loaded by Mixamo into the shown environment and can also be analyzed. This makes it possible to achieve a high degree of flexibility in the observation of the movement.

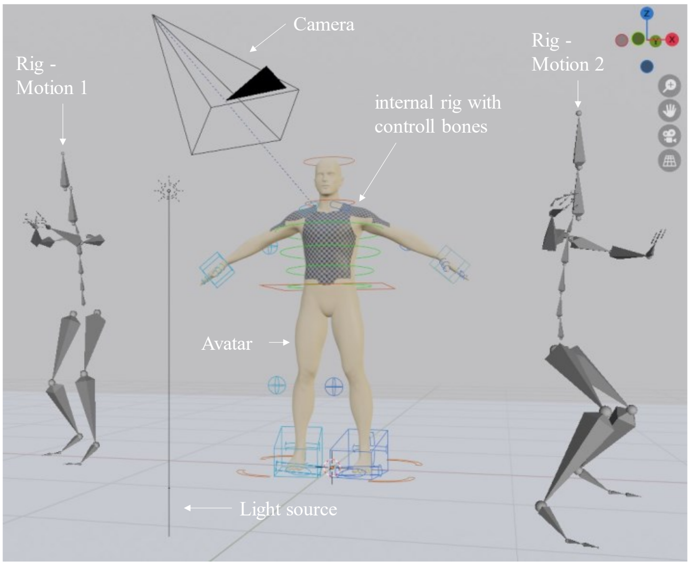

Fig. 3 Complete set-up of the animation in Blender.

Figure 4 shows the two movements – pulling a weapon (motion 1) and a defensive pose (motion 2) in the final position. When pulling the weapon (Fig. 4A), the avatar moves from a neutral position and reaches back, then straightens his arms. In the defensive pose Fig. 4B, the avatar moves forward from a step out (left foot in front) with the right foot, so that the avatar comes to rest for a moment with the right foot in front with the right arm outstretched. Then he moves backwards again and returns to the starting position.

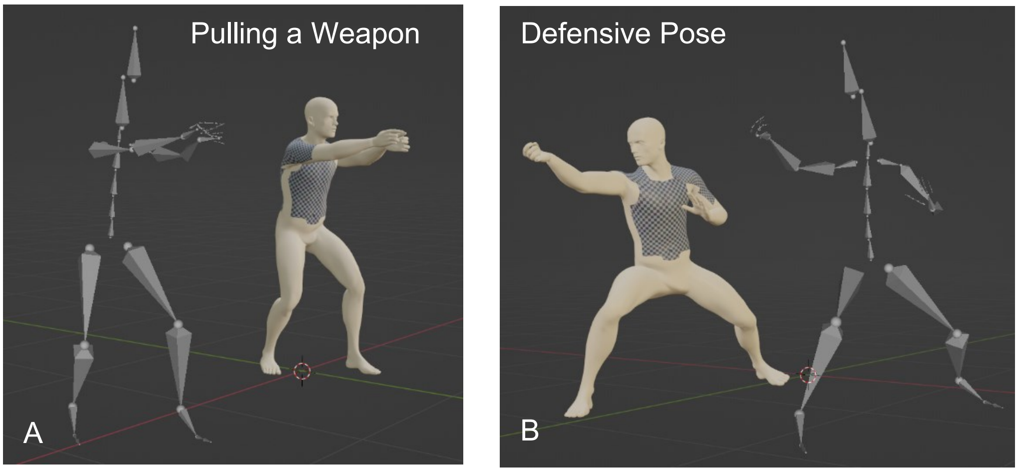

Fig. 4 The avatar with UV grid of the protective surfaces in place. The final positions of (A) pulling a weapon and (B) a defensive pose are shown.

3 Results and discussion

By applying the UV-grid to the avatar and the linked bone structure, it is now possible to view the movement more closely in Blender. This method makes it possible to view deformations and compressions of the UV-grid in the movement sequence. For this purpose, the individual frames of the movement were rendered and viewed in different camera perspectives. Four individual frames of the defensive pose are shown in Fig. 5 in different camera perspectives. If the individual frames and the grid are examined more closely, it can be observed that the squares of the grid are partially stretched and interchanged. It becomes clear in Fig. 5C in the area of the neck on the right arm (1), here the squares of the UV-grid are very compressed and very small. Otherwise, in the shoulder area, the UV grid and the squares are very stretched (2). It can also be seen that the movement causes the protective surface of the right arm to turn backwards (3). This leaves the forearm unprotected, which could be a potential risk in the event of an attack. Here the protective surface would have to be enlarged so that the forearm is also protected in such a movement. At the shoulder blade, on the other hand, the squares are enlarged and more consumed, which means that there is a lot of stretching. A high degree of flexibility is required at this point so that movement is not restricted when wearing a protective vest.

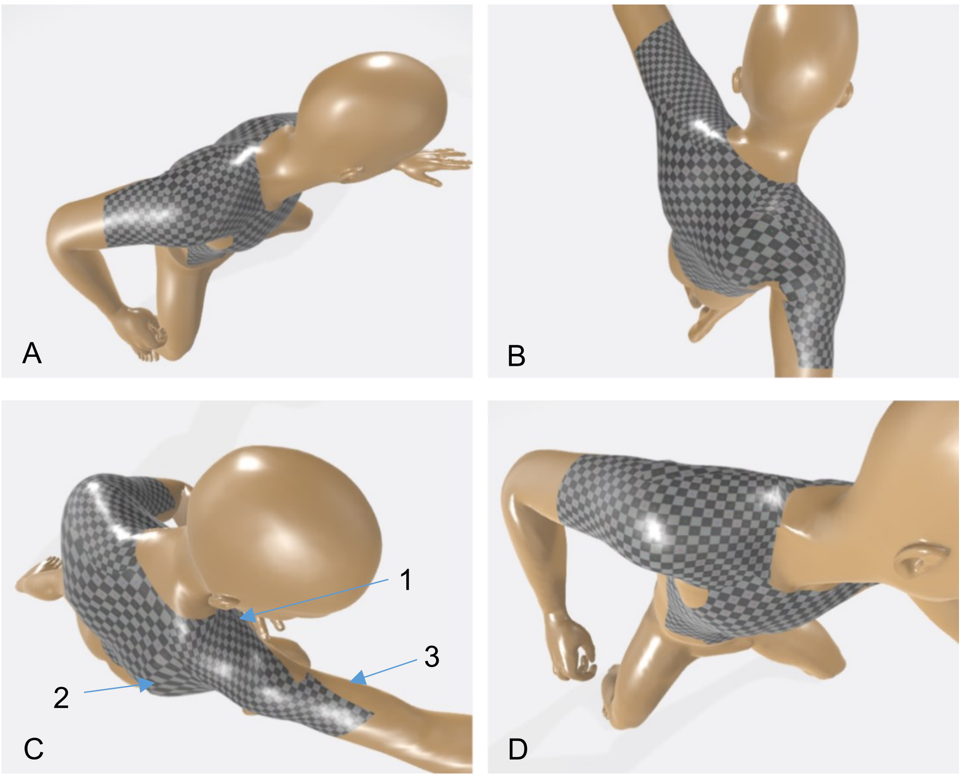

Fig. 4 (A-D) Four frames of the movement sequence "defensive pose".

Figure 6 shows the movement when pulling a weapon. During the movement, the deformation and compression is even more visible, especially in the final position when holding the forward pointing weapon, see Fig. 6D. The right shoulder blade shows clearly enlarged squares of the grid (2). In the area of the right arm (1) the squares are very reduced. At this point, the protective geometry may prevent the wearer from pointing the weapon forwards, as the protective elements prevent movement here. At the points shown, a high degree of flexibility is required with regard to stretching and compression, as otherwise the wearer's comfort and also the ability to react quickly may be restricted.

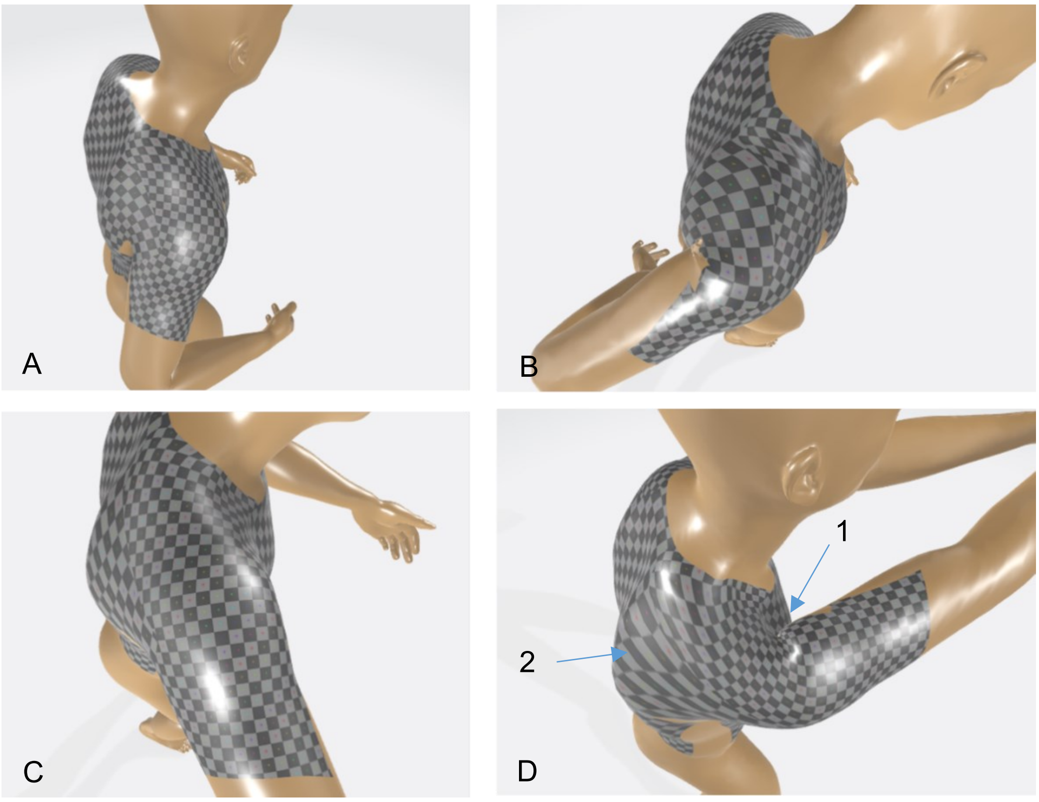

Fig. 6 Four frames (A-D) of the motion sequence "pulling a weapon".

The next step of a closer look at movements was not using an avatar, but human movements. For this purpose, probands and motions were scanned with the use of a 4D scanner "Move4D" from INSTITUTO DE BIOMECÁNICA DE VALENCIA (IBV). In the following, a defensive action based on the movement shown above is also considered. One proband was scanned and a total of 79 frames were recorded, which were then analyzed using a Python script. A curvature analysis of the body was performed from each frame. Curvature is a two-dimensional property of a curve and describes how much a curve is bent at a specific point on the curve. The shape around a point on a surface can be described by curvature projections. There are various calculation methods for describing curves (Gaussian, Mean, Min, Max or Curvedness) [16,17]. The maximum curvature analysis was chosen for the projection, as the maximum curvature at the respective point is of interest. The result was superimposed on the scanned body. Figure 7 shows only four frames of the total 79 frames of the proband's defensive movement. Curved areas are shown in red and blue. Green markings are areas where there is no or very little curvature. After the analysis, the individual frames were re-imported into Blender and reassembled into a movement. This makes it possible to replay the individual frames as a movement. The movement can then be viewed from different camera perspectives. By analyzing the movement, it is possible to visually display areas on the body where the curvature changes in the course of the movement and where it is highest. In the future, this can be used to optimally place protective geometries on the body. For this purpose, the size of the geometries can be adjusted. This makes it possible to achieve greater wearing comfort.

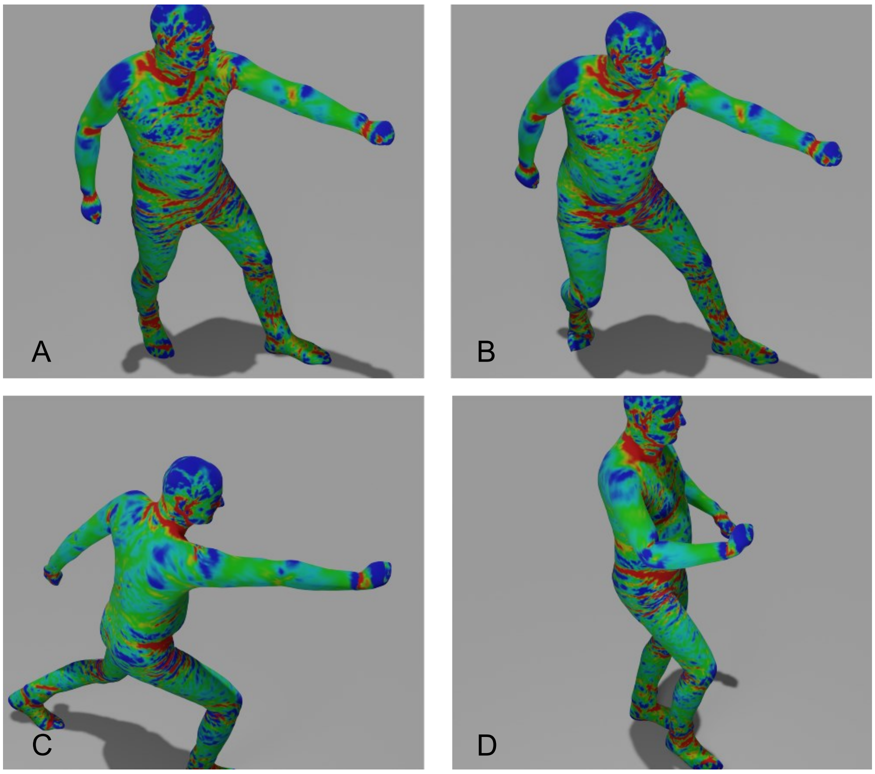

Fig. 7 Defensive movement with curvature analysis during movement. The four images (A-D) show a selection of the overall movement (red and blue areas show strongly curved areas).

For a better representation of the distortion, protective geometries in the form of rectangles are applied to the virtual avatar. Movements make the problem of deformation clearer. Figure 8 shows the protective plates on the avatar with Amar facing forward. At the right shoulder, the protective geometries pull apart, resulting in unprotected areas. It also shows areas where the protective geometries overlap, as Fig. 8 shows.

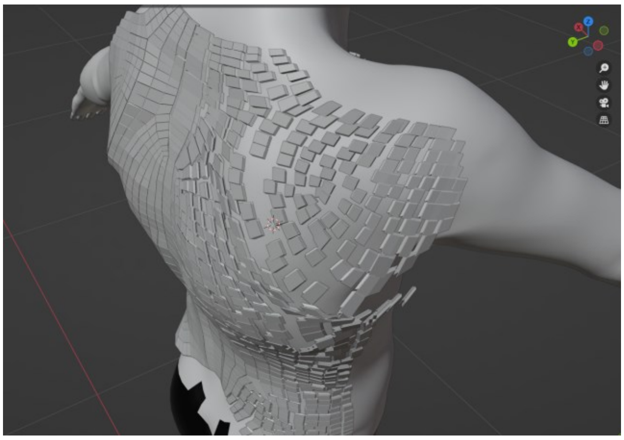

Fig. 8 Protective geometries applied directly to the virtual avatar with the arm stretched forward. The spaces between the geometries are visible when moving.

In reality, however, the protective geometries would not be directly connected to a body (avatar), but to a carrier material such as a textile. Therefore, in further steps, the simulation is to be further developed in which the geometries are applied to a textile. The subsequent simulation should then show the behavior during movement. First approaches have already been implemented in ready-to-wear programs. Today's ready-to-wear software solutions, such as Clo 3D, are not able to correctly represent the behavior of the protective geometries. In Fig. 9, protective geometries are applied to a T-shirt in Clo3D. During movements, collisions occur and the geometries "melt" with each other (shown in red), which does not correspond to reality. The individual geometries are not recognized as individual objects. Consequently, the simulation is not realistic during movement.

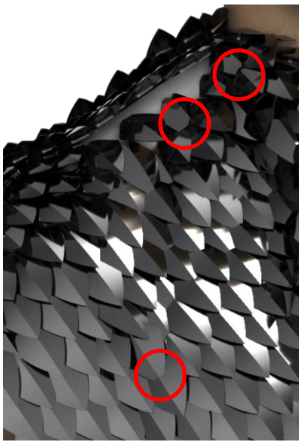

Fig. 9 Representation of protective geometries on textiles in the bent position. The red marks show problem areas where the protective geometries do not behave as in reality [13].

4 Conclusions and Outlook

Two methods for analyzing movements were presented. With the help of the first method (Blender), two movements, a protective stance and the drawing of a weapon, were considered. The Blender software was used for rigging, applying the UV grid and animating the movements. By applying the UV grid to protective surfaces of the upper body, it was possible to represent deformations and compressions that occur during different movements. The method presented allows each movement to be analyzed using Blender.

The second advanced method was performed with a Python script. By analyzing the curvature of each frame of the movement, the different maximum radii of curvature could be visually represented. By assembling the movement sequence in Blender, it is possible to view the movement from different perspectives and identify critical points. Since each person has an individual physique and also moves individually, the method shown can be used with each person and applied to their body curvatures. Through an animated rig, this can be linked to scanned individual bodies. This ensures that the movement is the same. Attention can be paid to the change in body curvatures, with the same movement. Therefore, the curvatures of different bodies can be compared.

In the future, protective geometries will be applied to a textile substrate and the movements used to identify critical areas where collisions or displacements of the protective surfaces occur. Different shapes of the geometries will also be considered, as they behave differently with movements and curvatures. The results can be used together with future simulations in conjunction with textiles to optimize the placement of protective geometries to achieve better protection on the one hand and improve comfort on the other.

Author Contributions

D. Muenks: methodology, formal analysis, investigation, conceptualization, writing- original draft preparation, visualization; Y. Kyosev: writing- review and editing, supervision, project administration; S. Xia: methodology, visualization, review.

All authors have read and agreed the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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