Quantifying the Dimensional Relationship Between the Interior and Exterior of Multi-layered Protective Gloves

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Background:
According to the U.S. Department of Labor, hand injuries account for nearly 11% of all lost-time industrial injuries, totaling approximately 130,000 cases in 2020 (U.S. Bureau of Labor Statistics, 2020). Such injuries can occur even when gloves are worn (Sokolowski & Griffin, 2020b), highlighting the need for better fit, as discomfort may cause workers to remove gloves and increase injury risk (Karwowski & Salvendy, 2010). Most protective gloves are made with multiple material layers to shield the hand from cuts, abrasions, heat, and hazardous substances. These added layers and thickness can also reduce hand performance and dexterity (Riley et al., 1985). The thickness of multi-layered materials increases the distance between the inner surface and the outer surface, further extending the distance between the actual hand and the exterior glove. This extended distance affects the interface between the hand and tool objects, which can negatively impact hand performance (Chang & Shih, 2006). For this reason, it is crucial to understand the relationship between the interior glove and exterior glove. However, while existing research has focused on fit through traditional anthropometry of the hand and the glove exterior (Kwon et al., 2008, Hsiao et al., 2015, Sokolowski & Griffin, 2020b), none have addressed the glove fit by considering both the exterior and interior layers together. To understand the fit interface between the interior and exterior, quantitative measures between the two layers need to be collected, and it is necessary to analyze the point-based relative distance (air gap) captured in the aligned state (S. Sokolowski et al., 2022; Yu et al., 2023). The objectives of this study are to examine the dimensional difference between the two layers using a traditional anthropometric approach and to quantify air gaps at critical fit landmarks to identify potential hindrances to dexterity.

Method:
The exterior and interior layers of three multi-layered welding gloves of the same size were separated and extracted through CT scanning. To achieve this, each glove was filled with moldable kinetic sand, allowing CT scans to distinguish the leather exterior from the interior due to density differences. 17 measurements were collected for both the exterior and interior of each glove using the computer-aided design software, Rhinoceros 3D. The measurements covered four zones: digit length, digit breadth, digit depth, and palm. These measurements were used to identify dimensional differences between the two layers. Furthermore, 27 landmarks were defined to quantify the air gap at critical fit locations by dividing the glove into four zones: the fingertip, the center of the finger (palm side), the finger web, and the palm zone. Using ZEISS Inspect, a 3D inspection and

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metrology software, the air gap distribution was visualized through a color deviation map (heat map) and the quantified air gap data were extracted and analyzed

Results:
The dimensional and air gap analyses revealed that the differences between the interior and exterior layers were pronounced in the digit area, specifically at the tip of the digit. When comparing the dimensional differences between the interior and exterior glove, the digit zone - digit length, breadth, and depth - showed mean differences of 5.7 mm, 11.53 mm, and 5.36 mm, respectively, with percentage differences of 14.33%, 36.22%, and 24.87%. These values were higher than those observed in the palm zone - 8.27 mm for palm length and 13.09 mm for palm breadth - with percentage differences of 5.62% and 9.01%, respectively. In terms of the air gap analysis, a heat map visualizing the air gap distribution by landmark, with the distance (max. distance: 10mm) between the interior and exterior show that the fingertip region exhibits an air gap ranging from a minimum of 7.25 mm to a maximum of 12.79 mm, indicating a more significant gap compared to other areas. The finger web area exhibited an air gap ranging from 3.12 mm to 5.78 mm, making it the second highest air gap observed among the finger zones. This implies that these larger air gaps at the fingertip and finger web, which affect dexterity, may lead to a sense of bulkiness for the users and potentially interfere with task performance.

Conclusion:
This study provides important insight into the sources of interference that limit hand performance, with the findings being particularly significant in the fingertip region, where such issues are more pronounced compared to other areas through the analysis of dimensional differences and air gaps. The findings underscore the need to address disparities between interior and exterior glove patterns to ensure better alignment of the interior glove at the web area and closer proximity of the two layers at the fingertips. This research of the relationship between the interior and exterior layers can be extended to the relationship between the human hand and both glove layers, contributing to a deeper understanding of functional improvement in human interaction.

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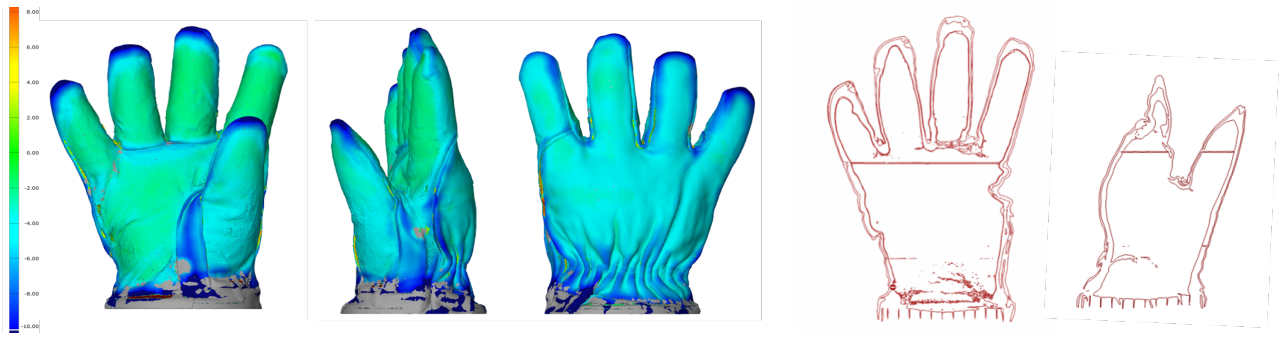

Figure 1. Heat map visualization for the air gap distribution and cross-section diagram

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