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# Optimized 3D printed wheelchair racing gloves

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*Abstract: Wheelchair racing gloves are often hand crafted from thermoplastics. The geometries are unique to the individual, often with thumb or finger cavities rendering line-of-sight laser scanning techniques inappropriate for full digital capture. This study describes the use of micro-CT to reverse engineer the bespoke hard gloves of an elite Paralympic athlete, with fabrication via 3D printing. Subsequent design changes, combined with the identification and manipulation of key process parameters during material extrusion, have demonstrated this approach affords enhanced glove performance. Preliminary rolling road test results suggest a competitive advantage for the athlete. The approach is believed transferrable within physical rehabilitation.*



## I. Introduction

Within wheelchair racing, there exists two competing styles of racing glove used to push against the rims of the chair itself [1]. The first is a soft, fabric mitten though this present study focused on the second, solid style. These hard gloves are frequently constructed from a PCL thermoplastic (e.g. Polymorph), with the addition of foam cushioning, and rubber friction pads. One Loughborough-based Paralympic athlete created a bespoke pair of racing gloves in this way, with the left and right gloves differing in geometry due to their handmade nature of construction. In recent times there has been a trend towards the digital capture of these bespoke glove geometries with 3D printing enabling lightweight alternatives to be made. This paper describes how reverse engineering, CAD and 3D printing were used to optimize the glove performance for this athlete.

## II. Material and methods

The athlete's homemade gloves were complex in design, incorporating a thumb and finger cavities and curved palm support. Consequently, micro-CT was used to fully capture all geometry during reverse engineering. From this scan, InVesalius [Renato Archer Information Technology Center, Brazil] software was used to create a 3D model of the thermoplastic part, see Figure 1, with density thresholding employed to filter out other materials.

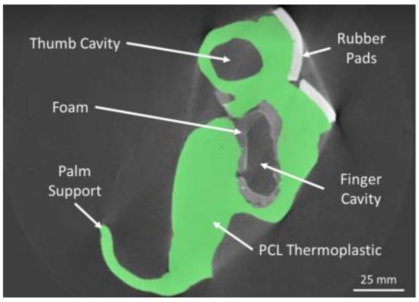


*Figure 1: Micro-CT scan image of glove. The green region shows the PCL thermoplastic area mask.*

This model was subsequently cleaned using Smoothing tools within Meshmixer software [Autodesk, U.S.], as also done in a similar, independent study [2]. This provided a baseline 3D CAD model identical in shape to the original Polymorph glove.

This baseline geometry was subsequently modified in CAD to try and enhance performance in certain race conditions. For example, decreasing the volume (lightweight design) to reduce user fatigue in distance races. Two methods of increasing the frictional contact area between the rubber pads and wheel rim were also considered (thumb build-up and augmented rim groove). In addition to these geometric design changes, the study examined various 3D Print parameters, such that the glove mass could be further reduced for the lightweight design, whilst being increased for the baseline geometry to create a heavy design, with greater impact forces and inertia for sprint races. In each case, after modification, the glove was mirrored in CAD to complete the glove pair. The final geometries can be seen below in Figure 2.

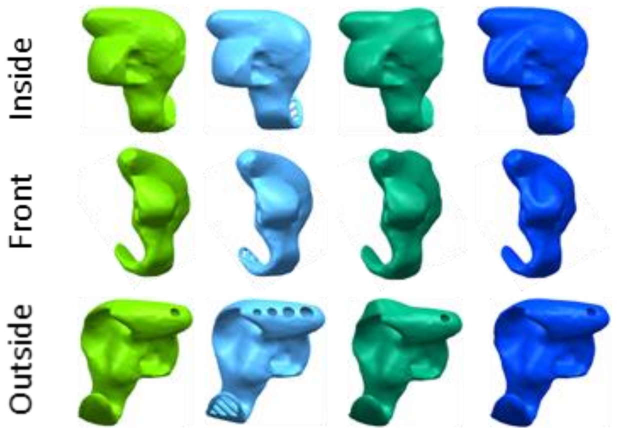


*Figure 2: From L-R, Baseline-Heavy, Lightweight, Thumb Build-Up and Groove prototype glove geometries.*

Wall thickness and infill % were selected as the most relevant material extrusion 3D printing parameters to investigate when trying to create gloves of different masses. As the loading of the gloves closely resembles a three-point bend test, samples were created in accordance with ASTM

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D790. Five samples were created for each parameter set, printed from standard PLA, in 0.15mm layers, on an Ultimaker 2+, before being tested on an Instron universal testing machine. The ultimate flexural stress (UFS), flexural modulus and mass of each sample was recorded and averaged for each build condition. Following, analysis of these results, the prototype gloves were manufactured with selected parameters on the same equipment. Each pair of gloves had foam cushioning and rubber pads added (~25g) and were then weighed prior to use.

The wheelchair gloves were tested on a rolling road at the National Centre for Sports and Exercise Medicine, at Loughborough University. This allowed measurement of the force, power and speed, of each wheel. For each of the four prototype gloves, a trial sprint of 25 seconds was conducted, equivalent to a 200m race, where ~50 push stokes are expected.

## III. Results and discussion

As shown in Figure 3, the three-point bend test highlighted that wall thickness influenced the mechanical properties (UFS) more than infill %.

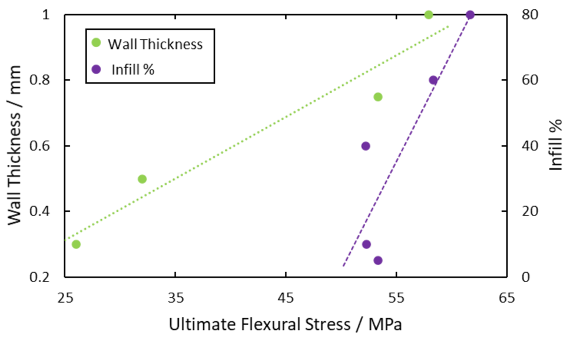


*Figure 3: Results of three-point bend test, showing how wall thickness and infill % affected UFS*

As a result, it was decided to maintain thicker walls of 1 mm and vary infill to change the mass of the gloves, to try and maintain structural integrity. This led to the glove parameters listed in Table 1.

*Table 1: Key parameters for each prototype glove.*

| | Baseline-Heavy | Lightweight | Thumb Build-Up | Groove |
|---|---|---|---|---|
| Volume [cm$^3$] | 155.4 | 145.7 | 160.3 | 153.5 |
| Infill % | 80 | 7 | 20 | 20 |
| Mass [g] | 174 | 70 | 94 | 81 |

The maximum force, power, and speed values (averaged from each pair) from the rolling road testing are shown in Table 2. Whilst the lightweight gloves achieved the greatest top speed, they lacked structural integrity, suffering mechanical failure 23 seconds into the test. This suggested the infill percentage was ultimately set too low at 7%.

The added groove achieved the highest maximum force, however this did not translate into the highest speed. Whilst this design shows good potential for enhanced performance, it relies on the groove repeatedly aligning with the wheel rim, which is not easy in practice. This was confirmed by the athlete witnessing a double impact sound, suggesting the modified shape hindered their technique during the pushes where the sweet spot was missed. As expected, the highest power was achieved by the heaviest glove and vice versa for the lightweight design.

*Table 2: Rolling road test results.*

| | Baseline-Heavy | Light | Thumb Build-Up | Groove |
|---|---|---|---|---|
| Maximum Force [N] | 123 | 118 | 116 | 127 |
| Maximum Power [W] | 1205 | 930 | 1117 | 1158 |
| Maximum Speed [ms$^{-1}$] | 10.55 | 10.81 | 10.77 | 10.60 |

## IV. Conclusions

This study has successfully demonstrated how reverse engineering via micro-CT, and subsequent data smoothing enabled the accurate digital capture of bespoke hard gloves with internal cavities, made from several materials. It has also shown how geometric modification of the 3D CAD model can enhance performance. However, greater improvements were seen when 3D print parameters were manipulated, specifically the infill % which heavily influenced the glove mass.

Whilst some conclusions have been drawn from the results, it should be noted that this is a preliminary study with only one test being performed for each glove pair. Consequently, the significance of any findings are limited and further testing is recommended. This would also help to identify whether the athlete tired or was performing consistently.

Future work could also include localized changes to print parameters, such as a higher infill % in impact areas with lower infill % elsewhere, or the use of materials with a greater strength to weight ratio. Both of these would allow for lighter gloves with superior mechanical properties.

The approach undertaken in this study has demonstrated that the performance of wheelchair racing gloves can be tailored to an application and individual, suggesting excellent crossover for medical rehabilitation.

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### Author's statement

Conflict of interest: Authors state no conflict of interest. Informed consent: Informed consent has been obtained from all individuals included in this study. Ethical approval: The research related to human use complies with all the relevant national regulations, institutional policies and was performed in accordance with the tenets of the Helsinki Declaration, and has been approved by the authors' institutional review board or equivalent committee.

### References

[1] I. Rice et al, *The Influence of Glove Type on Simulated Wheelchair Racing Propulsion: A Pilot Study*, Int J Sports Med, 37(1), pp. 30–35, Oct. 2015.

[2] D. Covill et al, *Development of Customised Wheelchair Racing Gloves Using Digital Fabrication Technique*, Proceedings, 49(1), pp. 44–49, Jun. 2020.