Quantifying Vision Obstruction of Formula One (F1) Halo Concept Variants

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Abstract

This paper presents an early-design methodology to quantify vision obstruction caused by halo-type cockpit safety equipment introduced into Formula One (F1) racing in 2018. The *halo* is a curved bar that surrounds the driver's head over the cockpit opening and offers additional protection to drivers. However, the halo's introduction has raised concerns over vision obstruction-related issues due to its vertical and horizontal bars (pillar-like elements) sitting in front of the cockpit. This study assesses vision obstructions by exploring the driver's forward field of view (FoV) based on the coverage zone analysis. This research utilizes digital manikins inserted in a digital F1 racecar mockup to assess the effects of halo concept variants on vision obstruction. The preliminary results showed that the vision obstruction was not only affected by the halo geometry and size but also the orientation of the F1 car in different racetrack segments. The methodology discussed in this study is critical for other early-stage product design and development challenges, where designers demand "quick-and-dirty" ergonomics evaluation of vision obstruction before building time-consuming and costly physical mockups.

Keywords: Preliminary Design, Human-Centered Design, Digital Human Modeling, Formula One, Vision Obstruction

1. Introduction

Past incidents in Formula One (F1) racing have resulted in severe injuries and deaths due to a lack of a cockpit closure. Advanced helmets have only provided limited protection to minimize the threat of rollover crashes and high-speed projectiles hitting the driver's head. Current F1 race cars have recently incorporated the *halo* safety device to mitigate the adverse effects of open cockpit racing to protect the driver's head. The halo is a curved bar attached to the F1 car at multiple points. It offers additional protection by surrounding the driver's head over the cockpit opening (Fig. 1). The generic halo safety device is made of titanium, weighs around 6 to 10 kgs, and is designed and manufactured by the Federation Internationale de l'Automobile (FIA). Although the halo device has brought an additional layer of improved safety to drivers, its introduction was unorthodox as it went against the aspect of the open cockpit racing style by creating a canopy-like

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cockpit enclosure. In addition, the halo design has received controversial reviews among F1 drivers and critics due to its potential to obstruct drivers' forward field of view (FoV) [1].

Mental and physical fatigue effects on a driver are known to be strenuous while operating an F1 car. The added visual fatigue due to maintaining an intensely focused driving for the entire race duration impacts the driver's overall performance. Hence, providing the driver with an unobstructed field of view (FoV) is crucial for safety and performance. The halo design introduces a narrower and more articulated vision through a semi-confined space, which can tax visual performance. Some critiques have also expressed concerns that the vertical bars included in the halo design may have compounding effects along with the sudden acceleration and deceleration throughout the race [2,3].

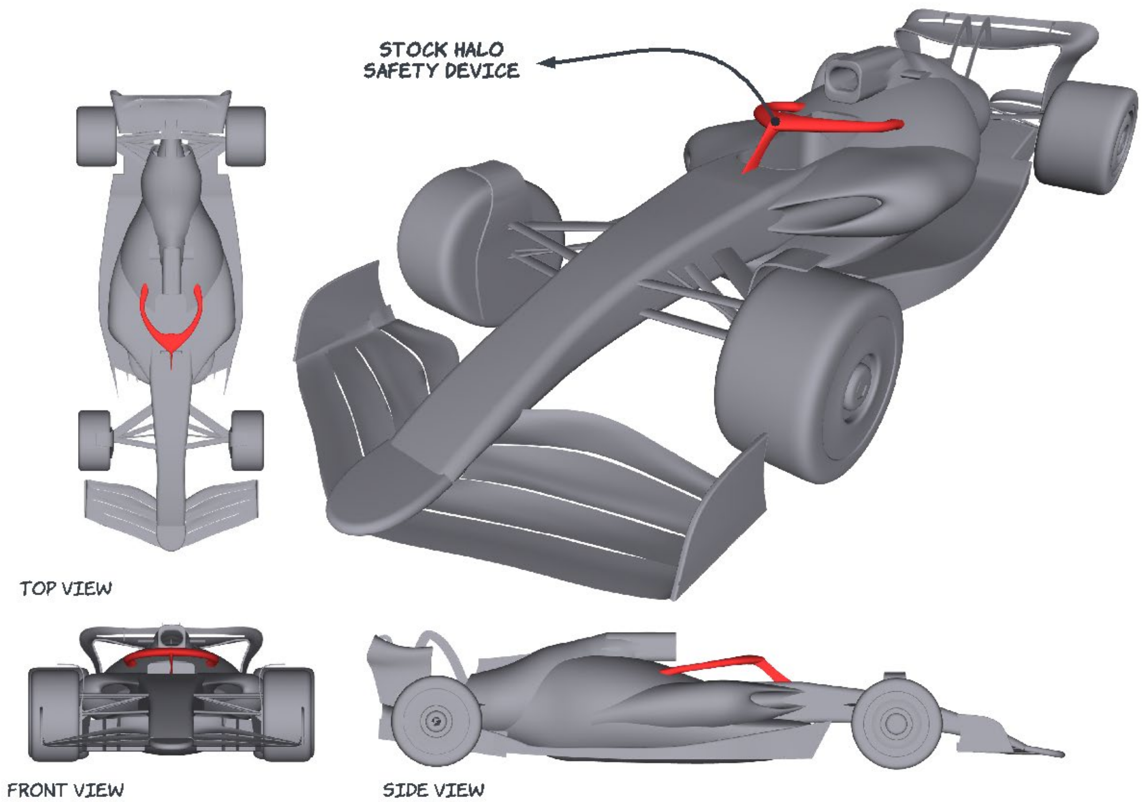

Figure 1. Generic 2022 F1 racecar model with the stock halo (in red) located over the cockpit opening.

The development F1 racing car reveals that cost often restricts the battle to meet performance requirements. The financial burden of prototyping and manufacturing costly bespoke physical prototypes is excruciating even for F1 teams. When designing for human factors engineering (HFE), the vehicle development process requires expensive mockups where any rework or retrofitting to correct ergonomics errors adds to the overall time and cost. Thus, early in design, the lack of proactive ergonomics impacts the final product's quality in terms of safety and usability, whether it's an F1 or a road-going car [5–7]. This study proposes a computational design approach that integrates DHM with visualization techniques to facilitate a "quick-and-dirty" vision obstruction assessment for concept halo variants.

2. Methods

Since having adequate visibility is critical for the safety and performance of operating an F1 car, we propose a preliminary design method to evaluate halo concept variants in terms of their performance in reducing drivers' forward vision obstruction zones. This research proposes a proactive ergonomics approach for early design concept evaluation of halo variants by integrating CAD, DHM, and VR (Fig. 2). The following subsections elaborate more on the model and simulation development.

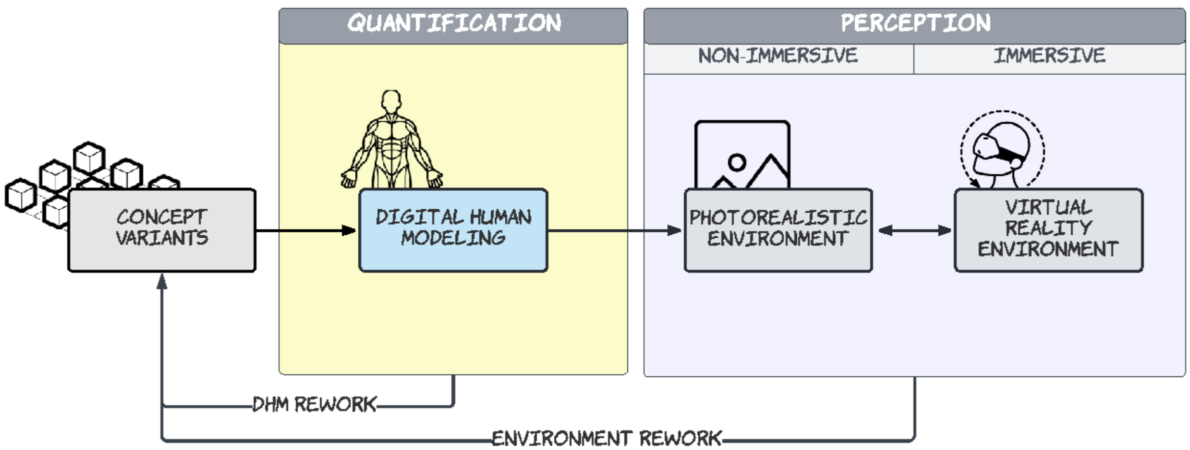

Figure 2. The methodology proposed in this paper provides opportunities to inject proactive ergonomics early in design. It links human modeling with photorealistic and virtual reality techniques.

2.1 Development of CAD Models:

A generic F1 2022 car model was created based on guidelines proposed by Formula One Group (FOM), which provides insight into the basic form and the development of body designs that are mandatory rules for teams. We used these guidelines to replicate a 1:1 scale CAD model to accommodate different halo concept designs (Fig. 3). Each halo model was created, modified, and adjusted to meet design requirements. Along with the vehicle and halo models, we modeled two different racing scenarios (based on racetrack segments) to illustrate cases where the opponent vehicle is blocked in the driver's vision by the halo. CAD models of the racetrack segments were created by considering the track width, length, and elevation changes. It is important to note that representing elevation changes in the CAD racetrack models was essential since a portion of this study focused on creating photorealistic and virtual reality environments to represent the racing scene with high fidelity (Fig. 4).

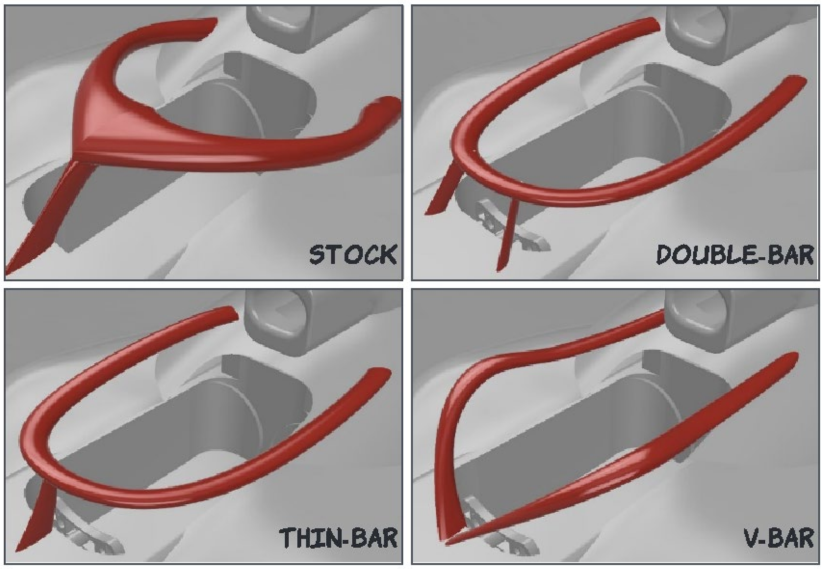

Figure 3. Concept halo design variants implemented on a generic 2022 F1 racecar model.

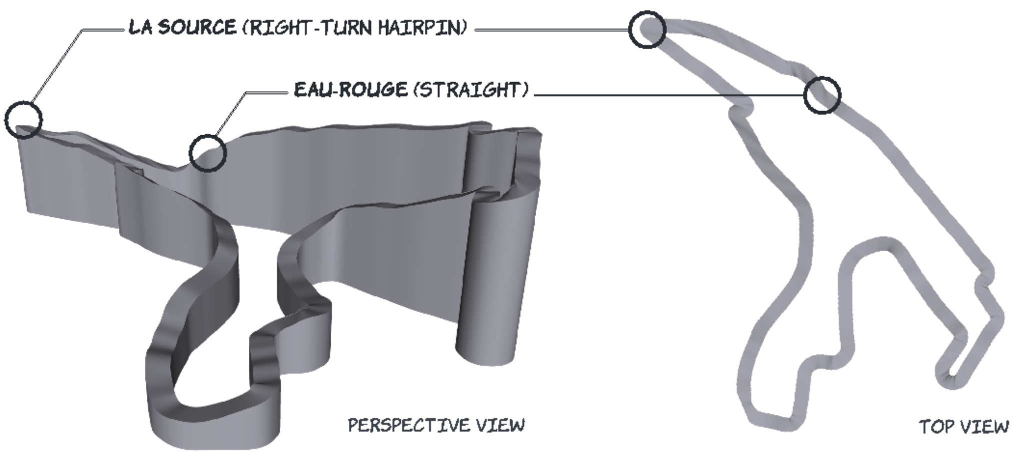

Figure 4. A simplified 3D CAD model of the Circuit de Spa-Francorchamps racetrack (La Source and Eau-Rouge segments) used in this study includes realistic elevation changes and track camber.

2.2 Digital Human Modeling Simulation Setup:

Prior research shows that incorporating HFE design principles in the early-stage design process can positively impact user interaction and the overall quality of products [8,9]. Applying proactive ergonomics with the aid of digital manikins enables engineers to discover potential design errors that can be identified and fixed before the physical prototyping process starts [10,11]. Further, in this study, we hypothesize that DHM-based design that combines high-fidelity models of the products and their use environments can help increase the success of injecting proactive ergonomics during early-stage design.

In this research, we created a computational representation of the racing environment, including the vehicles, racetrack, driver manikins, and environment objects, illustrating a simulation environment comparable to the real-life scenario. The integrated design framework proposed in this research intends to push the boundaries of traditional DHM what-if scenarios and extend the fidelity of early design assessments. This study uses a 3D model of the Belgium Circuit de Spa-Francorchamps racetrack, including realistic elevation changes and track camber (Fig. 4). We selected two segments from the racetrack: (1) the Eau-Rouge straight and (2) the La Source right-turn hairpin. These segments represent scenes of the racetrack where drivers are involved in overtaking maneuvers that require heavy vision concentration.

A 50th percentile male from the Anthropometric Survey of US Army Personnel (ANSUR) manikin database representing an F1 driver was seated inside the generic 2022 F1 cockpit. The manikin's head/neck joint (atlanto occipital) was adjusted based on a vision target (coverage plane) representing another F1 car ahead (Fig. 5). The posture represents typical scenarios of high-speed maneuvering of corners and the effect of cornering on the driver's posture. Meanwhile, another F1 car is situated on the track where it has stopped directly ahead by the distance covered in one second. For example, the F1 car is expected to enter the corner at 300 km/h and exit at 180 km/h. In the event of a mishap at this corner, the driver's reaction time demands less than one second. If this sub-second reaction time is missed, the driver will directly collide with the vehicle placed roughly 80 meters ahead immediately.

In this DHM study, the vision obstruction due to the presence of the halo design was measured using the *coverage zone* analysis in Siemens Jack software. The ray-casting-based vision analysis toolkit within Siemens Jack software was used for exploring vision obstructed by the pillar elements of the halo design (Fig. 6). While designing the DHM approach is superior in quantifying vision obstruction based on rough CAD and environment models, it lacks mimicking actual racing conditions. The absence of high-fidelity information regarding the use environment causes perception-related data only partially represented in DHM platforms. To overcome these issues, DHM models were imported into high-fidelity visualization (photorealistic and virtual reality) software to improve early design capabilities.

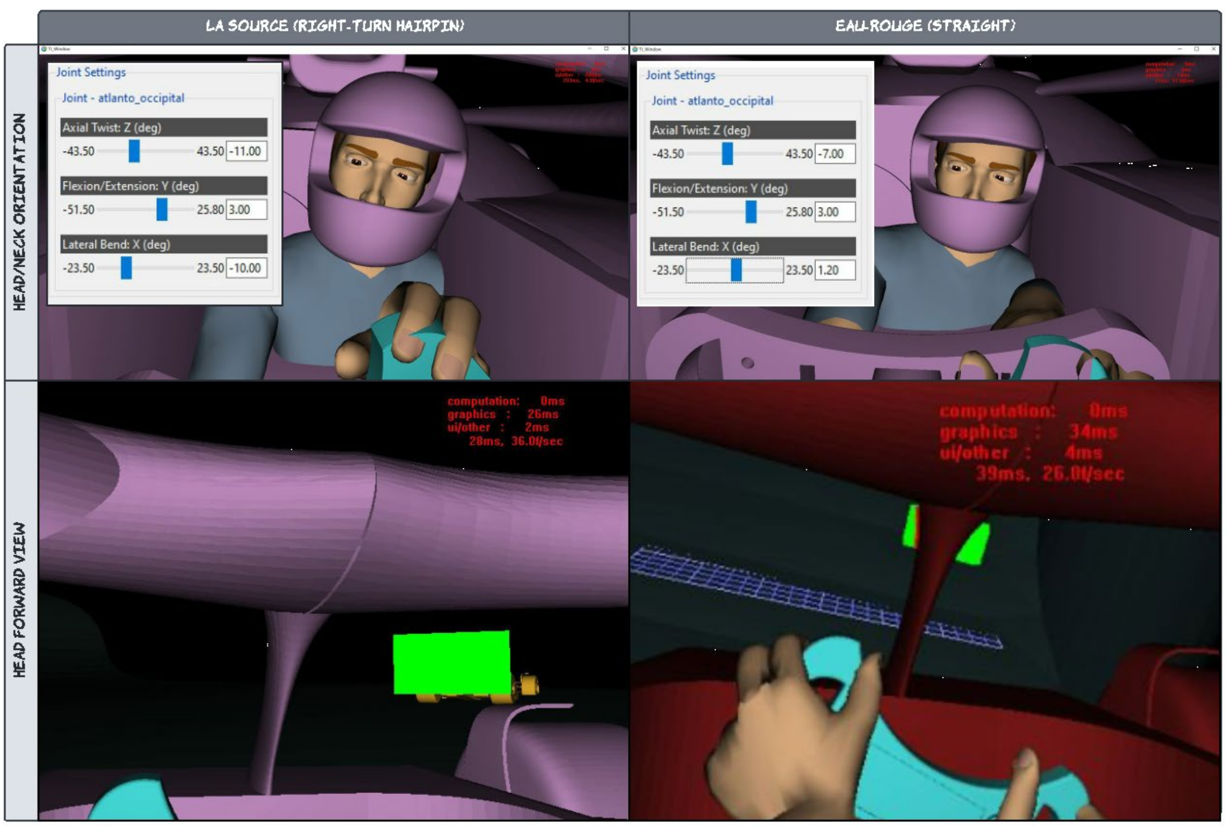

Figure 5. Head forward view of the driver with the stock halo used in *coverage zone* analysis.

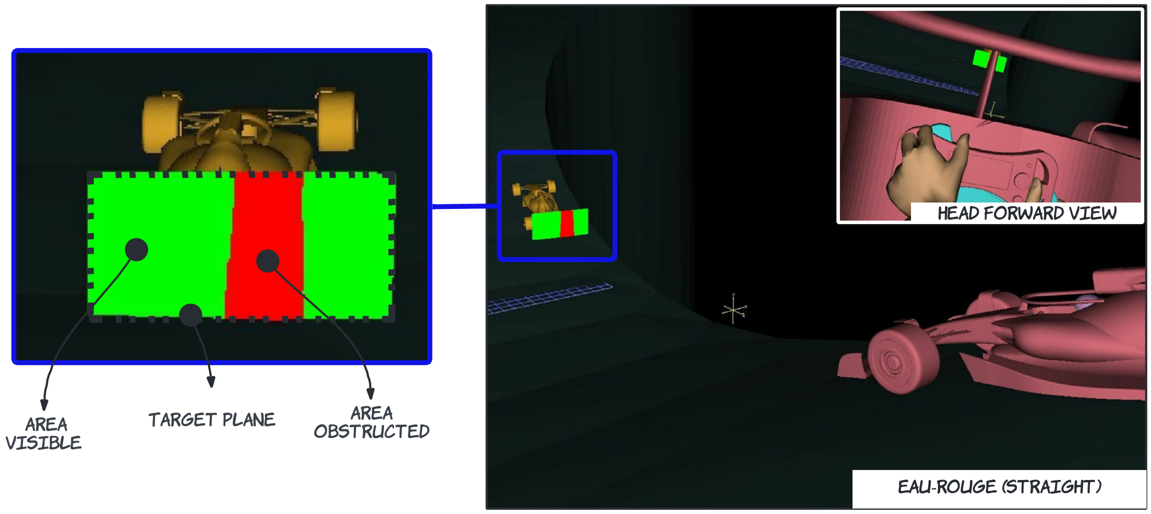

Figure 6. The image illustrates the *coverage zone* analysis performed in the 2022 F1 model with the thin-bar halo design. The area of the target plane (represented with dash lines) shaded in green represents the rays blocked by the vertical bar.

2.3 Photorealistic and Virtual Reality Environment Setup

Our current paper only focuses on the design and analysis efforts up to the photorealistic and virtual environment study. Our photorealistic (Fig. 7) and virtual reality (Fig. 8) studies are currently under development and will enable us to investigate the perception/cognitive aspects of the halo vision obstruction.

Figure 7. Photorealistic models and screenshots of the Spa racetrack from the VR environment.

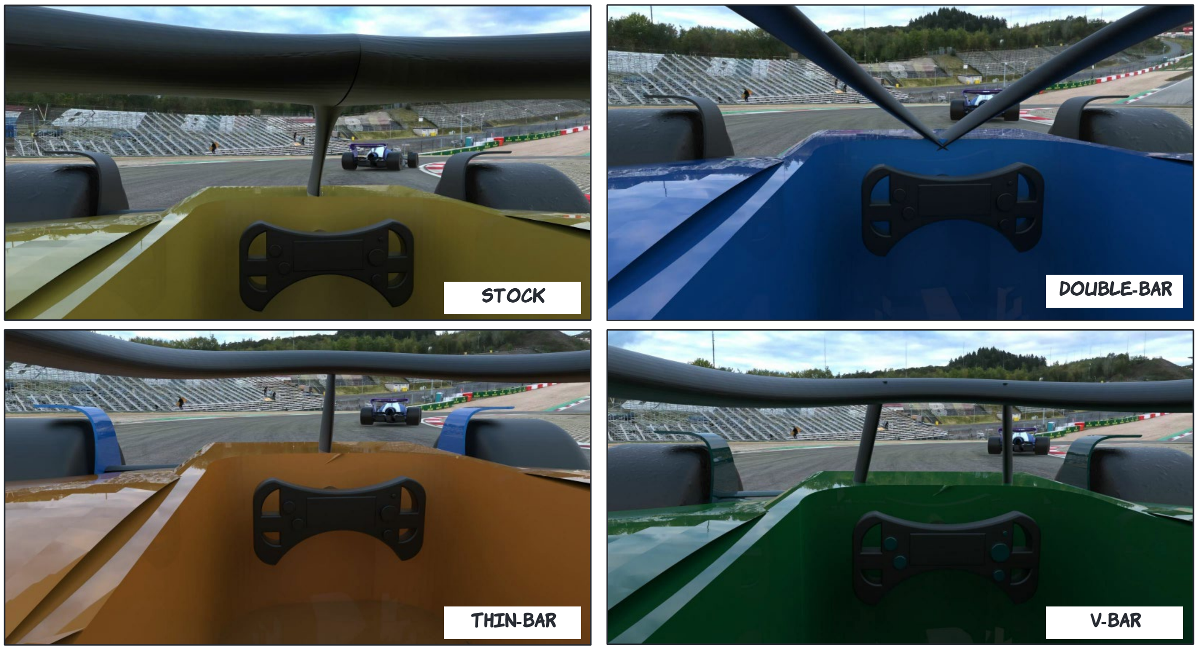

Figure 8. VR mockups of halo concept variants from the driver's point of view along with the high-fidelity visualization of the track segments.

3. Results

In this case study, we used *coverage zone* analysis to compare four halo concepts (illustrated in Fig. 3) in two track segments (La Source and Eau-Rouge) to measure percent visibility. The initial DHM assessments showed that the double-bar (100%) and v-bar (100%) halo models provided better visibility of the opponent vehicle when in the trough of Eau-Rouge on the Spa circuit. In contrast, stock and thin-bar designs only resulted in lower percent visibility, 32% and 75.4%, respectively. Likewise, the single wide central pillar design found in the stock (100%) and thin-bar (100%) halo variant models provide better visibility of the opponent vehicle during the La Source right-turn hairpin of the Spa circuit. In contrast, double-bar and v-bar designs yielded 84.6% and 55.4% visibility. These results indicate that the percent visibility of the forward field of view (FoV) vehicle varies based on the shape and size of halo designs and the track segment. Thus, no single design provides high visibility in both conditions. Different halo concept designs work differently based on track conditions and racing scenarios.

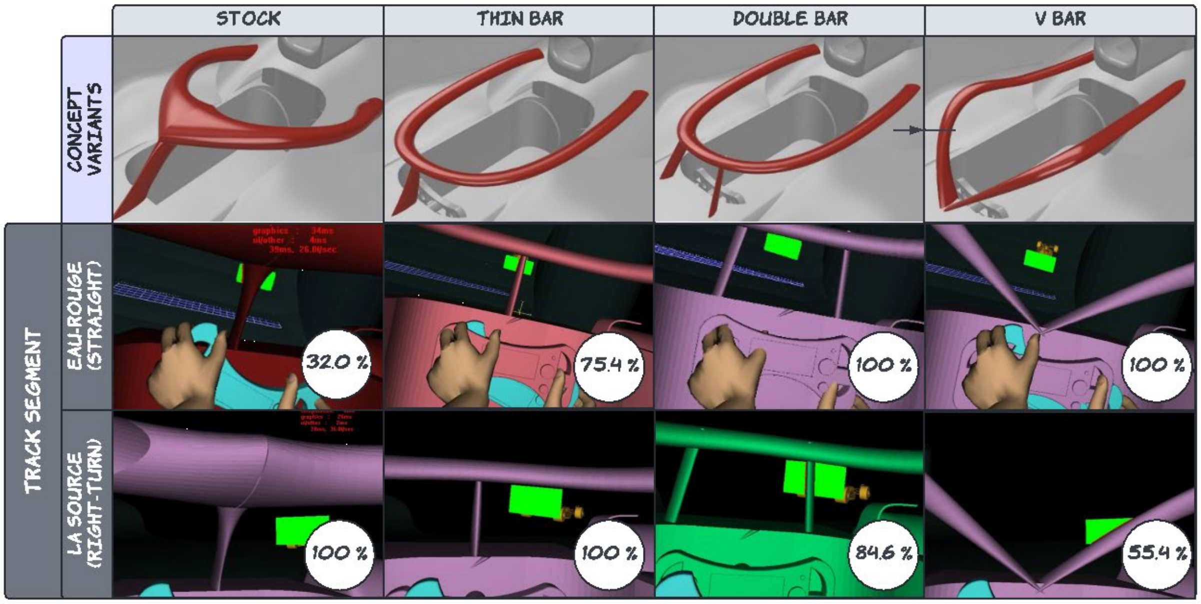

Figure 9. Visibility assessments (provided inside the callout bubbles) based on coverage zone outcomes indicate percent visibility in each scenario per halo concept variant.

4. Discussion and Conclusions:

While DHM simulation results are considered favorably for early design purposes, the simulation outcomes obtained in this study provide a limited understanding of vision obstructions caused by halo concept variants in F1 racing. The ray-casting approach used in *coverage zone* analysis utilizes static images on a 2D target plane, which lacks fidelity. There is a need to consider the effects of halo structure on human vision beyond investigating motion in 2D. Also, further development in DHM vision analysis should include factors such as perspective and depth of field.

There is also a need to replicate the dynamic nature of the simulation environment in DHM and VR studies to increase the fidelity further. Overall, integrating DHM and VR early in design allows the creation of a design feedback loop that minimizes the necessity of physical prototype testing and evaluation. Experiments for fit and feel using the VR setup would allow for a more robust design evaluation method by keeping humans (drivers) in the loop, which we plan to explore in our future studies.

Even with the introduction of dynamic driving simulation and advanced VR techniques, it remains challenging for any driver to identify and detect objects hidden behind the halo zone. Further research is needed to investigate halo variants that further minimize the obstruction zones. Models that use topology optimization and generative design techniques can help designers develop see-through zones (cut-out sections) on halo structure, which enables improved forward FoV.

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