ERGONOMIC EVALUATION OF CAR SEAT DESIGN USING RULA: A CASE STUDY OF THE UTEM SHELL ECO-MARATHON VEHICLE

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ABSTRACT: Ergonomic seat design is essential in automotive engineering to minimize musculoskeletal disorders (MSDs) and enhance driver comfort, particularly in compact vehicles such as Shell Eco-Marathon prototypes. This study applies the Rapid Upper Limb Assessment (RULA) framework to evaluate the ergonomic risks associated with the Universiti Teknikal Malaysia Melaka (UTeM) Shell Eco-Marathon car seat. Using CATIA-based modelling and Malaysian anthropometric data, driver posture was analyzed before and after seat modifications. The initial reclined seating position imposed elevated risks on the upper limbs due to extended leg posture and forward arm reach, resulting in a moderate RULA score of 3. A revised upright seating design improved spinal alignment, reduced shoulder elevation, and redistributed ergonomic risks resulting in a lower final score of 2. These adjustments achieved qualitative improvements in posture neutrality and driver comfort. The findings confirm RULA as a reliable tool for guiding ergonomic refinements in seat design and emphasize the importance of integrating anthropometric data into automotive ergonomics.

KEYWORDS: *Ergonomics; Human Posture; Musculoskeletal Disorders (MSD), Rapid Upper Limb Assessment (RULA), CATIA.*

1.0 INTRODUCTION

Ergonomics is a critical aspect of automotive design, particularly in seating systems where driver comfort, safety, and musculoskeletal health must be prioritized. Poorly designed seats can lead to awkward postures, restricted circulation, and increased risk of musculoskeletal disorders (MSDs), especially during prolonged driving [1]. These risks are amplified in compact vehicles such as Shell Eco-Marathon prototypes, where space constraints often compromise ergonomic standards [2]. Prior study also highlighted that seat comfort directly influences driver performance and safety, with poor lumbar support linked to fatigue and reduced concentration [3]. While ergonomic principles are well established, their application in compact prototype vehicles remains limited. Many studies focus on conventional automotive seating, but fewer address the unique challenges of competition vehicles, where performance and compactness often outweigh ergonomic considerations. There is a need for structured evaluation methods that can identify posture-related risks and guide design refinements in these specialized contexts.

The Rapid Upper Limb Assessment (RULA) is a widely recognized tool for evaluating posture-related risks in the neck, shoulders, arms, and wrists. By classifying body segments and assigning risk scores, RULA enables designers to identify hazardous postures and propose corrective measures. Recent studies confirm its reliability in ergonomic evaluation of seating systems and its effectiveness in guiding design modifications [4]. Previous studies also demonstrated its applicability in repetitive task and automotive contexts [5]. When combined with digital modelling software such as CATIA, RULA provides a structured approach to analyse seating ergonomics and integrating anthropometric data into design refinements [6]. Accordingly, the objective of this study is to apply the RULA framework, supported by CATIA modelling and Malaysian anthropometric data, to evaluate and improve the ergonomic suitability of the UTeM Shell Eco-Marathon car seat.

2.0 LITERATURE REVIEW

2.1 Ergonomics for Car Seat

Automotive seating is a primary determinant of driver comfort, safety, and musculoskeletal health. Poorly designed seats contribute to prolonged static postures, restricted circulation, and increased risk of MSDs, including lower back pain and whiplash injuries [1]. Ergonomic seat design emphasizes lumbar support, cushioning, and adjustability to maintain spinal neutrality and reduce muscular strain. Recent studies confirm that upright seating with proper lumbar contouring significantly lowers ergonomic risk scores and improves endurance during prolonged operation [2][7]. Earlier reviews also emphasized that seat contouring and cushioning are critical to reducing fatigue and improving comfort in long-duration driving [3].

2.2 Anthropometric in Car Seat Design

Anthropometric data is essential for designing seats that accommodate diverse driver populations. In Malaysia, average height, weight, and body proportions provide critical parameters for ensuring accessibility and comfort across different statures. Adjustable features such as seat height, backrest angle, and seat depth allow drivers of varying body sizes to achieve posture neutrality and efficient pedal reach [8]. Recent ergonomic evaluations highlight that integrating anthropometric data into seat design reduces musculoskeletal risks and enhances overall driving experience [4][9][10]. Earlier Malaysian studies also confirmed the importance of localized anthropometric datasets for automotive seat design [11].

2.3 Ergonomic Evaluation Tools

The Rapid Upper Limb Assessment (RULA) has been widely validated as a reliable method for posture-related risk evaluation, particularly in seating ergonomics. Research confirms its effectiveness in guiding ergonomic refinements in both industrial and automotive contexts [12]. Earlier work demonstrated its applicability in repetitive task evaluation and quality inspection, reinforcing its robustness across domains [5]. Complementary tools such as the Rapid Entire Body Assessment (REBA) and digital human modelling in CATIA further enhance ergonomic evaluation by providing whole-body analysis and simulation capabilities [2]. These tools, when combined with anthropometric integration, offer a comprehensive framework for ergonomic assessment in vehicle design.

While ergonomic principles and evaluation tools are well established, their application in compact prototype vehicles such as Shell Eco-Marathon cars remains limited. Most studies focus on conventional automotive seating, with less emphasis on competition vehicles where performance and compactness often compromise ergonomics. This study addresses this gap by applying RULA, supported by CATIA modelling and Malaysian anthropometric data, to evaluate and refine the ergonomic suitability of the UTeM Shell Eco-Marathon car seat.

3.0 METHODOLOGY

3.1 Conceptual Seat Design

The design process began with a review of ergonomic principles and anthropometric data relevant to Malaysian drivers. Key parameters such as average height, leg length, and torso proportions were considered to ensure that the seat design accommodated a wide range of body sizes [8]. Literature on ergonomic seating highlighted the importance of lumbar support, seat depth, and backrest angle in reducing musculoskeletal strain [2].

3.2 Digital Modelling and Refinement

The conceptual design was translated into a three-dimensional model using CATIA software. This allowed for precise visualization of seat dimensions, angles, and adjustability features. Iterative refinements were made to improve posture neutrality, focusing on seat height, backrest contour, and cushioning thickness. The digital model also facilitated simulation of driver posture, enabling early identification of potential ergonomic issues before physical prototyping [13].

3.3 Integration of Anthropometric Data

Malaysian anthropometric measurements were integrated into the evaluation to ensure inclusivity and usability across diverse driver populations. Seat height, depth, and backrest angle were cross-checked against local datasets to confirm accessibility for both shorter and taller drivers [10]. This ensured that the design modifications were not only ergonomically sound but also population-specific, enhancing comfort and safety for a broad user base.

3.4 Final Design

To ensure ergonomic suitability, the final seat design was developed with strict adherence to anthropometric data and ergonomic principles. The specifications were defined based on Malaysian driver measurements, including average stature, leg length, and torso proportions, to accommodate a wide range of users. Key parameters included seat height, backrest angle, seat depth, and cushioning thickness, all adjusted to promote posture neutrality and minimize musculoskeletal strain.

A detailed 3D model of the seat was created using CATIA to visualize and validate the design. The model incorporated essential components such as the seat base, contoured backrest, and headrest. The backrest was designed with a slight curvature to support the lumbar region, while the seat depth was optimized to prevent excessive thigh pressure and ensure efficient pedal reach. Adjustable features were integrated to allow drivers of varying statures to achieve comfortable alignment, including seat height adjustment and backrest recline.

Figure 3.1 illustrates the transition from the initial seat configuration to the revised ergonomic design. The original seat design positioned the driver in a reclined posture with limited lumbar support and extended leg reach, which contributed to elevated musculoskeletal risks. In contrast, the revised design incorporates a more upright seating position with improved backrest contouring and optimized seat depth, promoting spinal neutrality and reducing static muscular load in the upper limbs. This visual comparison highlights how ergonomic refinements in seat geometry directly influence driver posture and comfort, forming the basis for subsequent RULA evaluation.

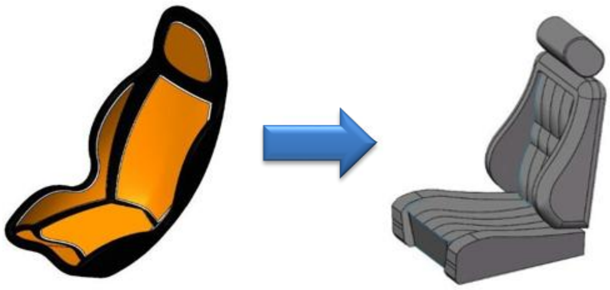

Figure 3.1: Before and after seat design modification

3.5 Ergonomic Evaluation Using RULA

The ergonomic risks associated with the seat design were evaluated using the RULA framework. Driver posture was systematically observed and classified into RULA body segments, including neck, shoulders, arms, and wrists. Each segment was scored based on posture deviation, muscle use, and load, with scores ranging from 1 (low risk) to 7 (high risk) [4]. Prior studies confirmed RULA's effectiveness in repetitive task and automotive contexts, reinforcing its suitability for seat ergonomics [5].

Driver posture was then classified into RULA body segments (neck, shoulders, arms, wrists, and hands), with consideration of how vehicle design elements, such as cab dimensions, headroom, legroom, and control placement—influence ergonomic risk. Previous studies have shown that poor visibility, vibration exposure, and seat design are major contributors to neck strain, muscle fatigue, and lower back discomfort [7][14]. Seat parameters such as adjustability, lumbar support, backrest angle, seat depth, and cushioning were analysed to determine their adequacy in supporting driver posture.

Following classification, posture scores were calculated using the RULA scoring chart, which assigns values from 1 (low risk) to 7 (high risk). Strict adherence to the scoring procedure was maintained to ensure accuracy. The individual scores were then aggregated to produce an overall RULA score, representing the cumulative risk of MSD development. A high overall score indicates the need for corrective measures to reduce ergonomic risks.

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4.0 RESULTS AND DISCUSSION

4.1 Seating Position Before Modification

In the initial design as shown in Figure 4.1, the driver was positioned in a low, reclined posture with legs extended forward and the torso leaning back against the chassis. This resulted in elevated scores for the arms and wrists, reflecting awkward positioning and static muscular load.

Figure 4.1 Initial seating position

The final RULA score of 3 indicated moderate risk, with the most critical concern being upper limb strain (Figure 4.2). These findings are consistent with prior studies showing that reclined seating often increases musculoskeletal risk in the upper body due to poor reach and wrist alignment [3][7].

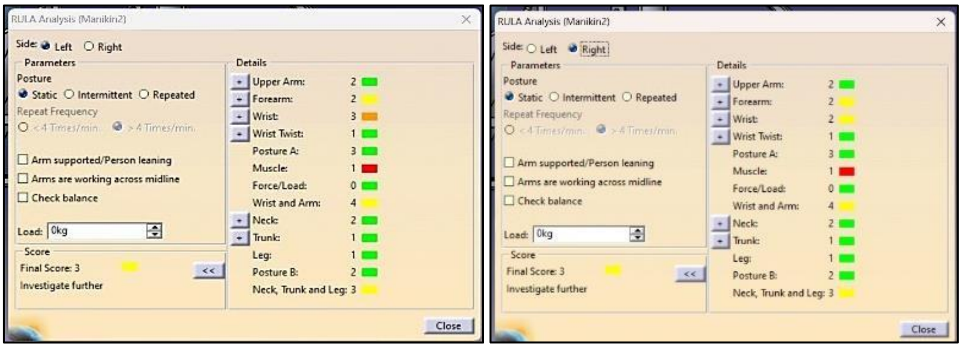

Figure 4.2: Final RULA score (left and right) for initial design seating position

4.2 Seating Position After Modification (Revised Design)

The revised design (Figure 4.3) shifted the driver into a more upright and elevated seating position. Ergonomically, this adjustment reduced static muscular load in the upper limbs by minimizing shoulder elevation and forward lean. Comparative studies confirm that upright seating with proper lumbar support significantly reduces musculoskeletal strain and improves ergonomic scores in vehicle and workstation contexts. Earlier ergonomic evaluations also emphasized that lumbar contouring and cushioning are critical to reducing trunk strain [7][14].

Figure 4.3 Seating position after modification (revised design)

Comparing both positions, the initial design prioritized vehicle performance and compactness but compromised driver comfort and long-term musculoskeletal health. The revised design, by contrast, balances performance with ergonomics, ensuring that the driver maintains a posture closer to neutral alignment. This reduces the likelihood of MSDs, enhances endurance during prolonged operation, and improves safety by minimizing fatigue-related risks. Recent studies confirm that ergonomic interventions in seating design significantly reduce musculoskeletal strain and improve posture quality in vehicle and workstation contexts [4].

Figure 4.4 Final RULA score (left and right) for revised design seating position

In the revised design, the driver's posture was adjusted to a more upright position with bent legs and closer steering wheel placement. These changes reduced strain on the arms and wrists, reflected in lower segment scores (1–2 for forearm and wrist). The trunk score remained moderate but manageable, while the overall RULA score improved to 2, indicating acceptable ergonomic performance. This redistribution of risk factors demonstrates progress toward ergonomic balance, suggesting that the current seat design provides sufficient support, consistent with findings from comparative ergonomic studies [16].

Overall, a final RULA score of 2 for the revised seating position represents a qualitative improvement and no further action is required. The ergonomic risks have shifted away from the upper limbs and toward the trunk, which is more manageable through seat contouring and lumbar support modifications. This aligns with recent systematic reviews confirming that RULA remains a reliable tool for identifying posture-related risks and guiding ergonomic interventions in vehicle and industrial design contexts [4]. In conclusion, the ergonomic evaluation demonstrates that the revised seating position represents a significant improvement over the initial design. By incorporating principles of posture neutrality, spinal support, and optimized reach, the new configuration aligns with RULA-based recommendations and provides a safer, more comfortable environment for the driver.

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study applied the Rapid Upper Limb Assessment (RULA) to evaluate ergonomic risks in the Shell Eco-Marathon chassis. The initial reclined posture produced higher risk scores for the upper limbs, indicating musculoskeletal strain in the arms and shoulders, with a final RULA score of 3. Following design modifications, the driver's posture shifted to a more upright position with bent legs and improved spinal alignment, which reduced upper limb strain and yielded a lower final RULA score of 2. The revised configuration demonstrated improved ergonomic balance and greater driver comfort. These findings are consistent with research showing that upright seating with lumbar support reduces musculoskeletal strain and confirms that RULA is a reliable tool for guiding ergonomic interventions in vehicle design.

5.2 Recommendations

To further enhance driver safety and comfort, it is recommended that the seat design be optimized with adjustable lumbar support, contoured cushioning, and flexible seat depth to accommodate a wide range of anthropometric profiles. These improvements will reduce trunk strain, improve spinal alignment, and minimize pressure points during prolonged operation. In addition, the steering wheel and pedal controls should be positioned within optimal reach zones, with adjustable mechanisms to suit drivers of varying statures. Such refinements will minimize awkward postures, reduce static muscular load in the upper limbs, and improve overall ergonomic performance.

Structural refinements, such as modifying the roll cage geometry, can ease ingress and egress, lowering physical strain during entry and exit. Future evaluations should complement RULA with tools like REBA to capture whole-body posture risks. Integrating these ergonomic findings into a Quality Function Deployment (QFD) framework will ensure that design modifications meet both technical requirements and user comfort expectations, achieving a balanced integration of performance, safety, and ergonomics.

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