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Ergonomic Assessment of Driver Posture in Prototype Vehicles for Kontes Mobil Hemat Energi (KMHE) Using CATIA

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ABSTRACT

The ergonomic design of the cockpit is crucial for improving driver comfort and safety, particularly in prototype vehicles for energy efficiency competitions. This study evaluates the driver's body posture using the Rapid Upper Limb Assessment (RULA) technique to propose design improvements that support better posture and reduce physical strain. The research methodology includes analyzing musculoskeletal risk levels through RULA, supported by the Human Activity Analysis tool in CATIA. The evaluation was conducted on the FT UNP prototype car in the Kontes Mobil Hemat Energi (KMHE), revealing a RULA score of 6, indicating a high risk of musculoskeletal issues. The findings suggest the need for redesigning the cockpit to enhance posture, including adjustments to the seat tilt, steering wheel position, and pedals. These ergonomic improvements are expected to reduce driver fatigue, enhance performance, and minimize injury risks.

Keywords
Ergonomics, Anthropometry, Posture, RULA, KMHE

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INTRODUCTION

The worldwide accessibility of energy sourced from fossil fuels, especially oil and natural gas, is presently exhibiting a downward trajectory [1]. An official announcement from the Ministry of Energy and Mineral Resources (ESDM) (Press announcement No. 0.28.Pers/04/SJI/2021) indicates that Indonesia's fossil energy reserves are anticipated to be exhausted in the foreseeable future. In the absence of new discoveries, petroleum is anticipated to be depleted within nine years. Simultaneously, natural gas and coal are anticipated to last for around 22 and 65 years, respectively. This predicament highlights the imperative for the government to promote the advancement of high-efficiency automobiles as a strategic measure to achieve sustainable solutions that diminish reliance on fossil fuels [2].

The National Achievement Center (Puspresnas), part of the Ministry of Education, Culture, Research, and Technology (Kemdikbudristek), conducts the Energy-Efficient Car Competition (Kontes Mobil Hemat Energi, KMHE), a national event designed to assess participants' proficiency in designing efficient and eco-friendly vehicles. Ergonomics is a vital consideration in the design process of electric vehicles, especially those intended for competitive use [3][4]. Therefore, vehicles engaged in this competition must incorporate ergonomic concepts in cockpit design to guarantee driver comfort.

Numerous studies have examined the musculoskeletal risk levels in vehicles engaged in competitions. Gunev and Iliev assessed the equilibrium of ergonomic parameters to ascertain the driver's ergonomic position in a prototype car developed by the Avtomobilist team at the University of Ruse, utilizing CATIA modeling and numerical posture analysis. The conclusive evaluation of the driver's position indicated that 63.5% achieved an optimal balance between driving comfort and engineering goals [5]. Fajar Santosa conducted a research utilizing the Rapid Upper Limb Assessment (RULA) approach to evaluate the architecture of the driver's cabin in a 2 kW electric vehicle. The study performed with CATIA software indicated a musculoskeletal disease (MSD) risk level for the driver's posture, resulting in a final score of 3, categorized as low risk [6]. The RULA approach is useful in analyzing individual work posture, particularly for seated occupations, in addition to determining musculoskeletal risk for drivers. A research conducted by Gozali et al. (2024) on administrative personnel at PT PLN revealed that three respondents attained an RULA score of 5, signifying a substantial risk of musculoskeletal disorders [7].

This study is the first to analyze the ergonomic design of the cockpit in the FT UNP prototype vehicle. No previous research has specifically assessed the driver's posture and musculoskeletal risks in this vehicle. The RULA method was chosen as it is widely used to analyze ergonomic risks for drivers, particularly in prototype vehicles used in competitions such as the Energy-Efficient Car Competition (KMHE) and the Shell Eco-marathon. The simulation was conducted using a digital mannequin in CATIA software to obtain the risk score. The novelty of this research lies in the specific application of this method to the FT UNP prototype vehicle. The findings are expected to provide a foundation for improving cockpit design to enhance ergonomics, comfort, and driver performance.

Prototype Vehicle

A prototype vehicle is a future-oriented vehicle specifically designed to optimize efficiency with various types of propulsion systems to achieve maximum fuel consumption during its operation [8]. This future vehicle is designed with an optimal aerodynamic structure and high energy efficiency. It features a three-wheel configuration, with two wheels at the front and one at the rear, and is driven by a single driver. The body design not only focuses on reducing aerodynamic drag but also serves to protect vital components such as the engine, transmission system, steering, braking, and electrical installations from external environmental influence [9].

Ergonomics

Ergonomics is the scientific discipline that examines the interaction between humans and the components of the systems they utilize, aiming to improve user comfort, safety, and well-being while maximizing overall system performance. This discipline encompasses the utilization of ideas, principles, data, and methodologies to design work environments, equipment, and jobs that correspond with human capabilities and constraints [10]. Ergonomic risks may result from discrepancies between the worker and the working environment, potentially causing accidents, health issues, and operational faults in equipment and system [11]. This method is an essential preliminary measure to guarantee the right implementation of remedial measures and controls, hence enhancing workplace safety and reducing accident risks [12].

Musculoskeletal Disorders (MSDs)

Musculoskeletal disorders refer to complaints arising from muscles and other skeletal structures, which can range from mild to severe. When muscles are continuously subjected to static loads over extended periods, this can lead to damage to joints, ligaments, and tendons [13]. This is supported by research that found a statistically significant relationship between work duration, work posture, and physical workload with musculoskeletal disorder (MSD) complaints among workers in the Roof Tile Industry Center in Sidoluhur Village, Godean District, Sleman Regency [14].

Anthropometry

Ergonomics is a scientific discipline that amalgamates scientific, artistic, and technological methodologies to establish a harmonious relationship between individuals and the instruments utilized in their tasks and leisure. This methodology takes into account the physical and mental abilities and constraints of individuals, aiming primarily to enhance overall quality of life [15]. Moreover, in the domain of nutrition, anthropometry is employed to evaluate an individual's nutritional status [16].

Rapid Entire Body Assessment (RULA)

RULA is a methodology employed to assess musculoskeletal problems, especially in the upper extremities. Formulated by Lynn McAtamney and Nigel Corlett in 1993, this method quantifies the physical stress on the body, emphasizing the pressure applied to various regions, including the abdomen and neck, among other areas [17].

The RULA method is a systematic technique for assessing ergonomic risk by analyzing workers' postures during task execution. This evaluation encompasses variables like as joint angles, muscle tension, and movement frequency, facilitating the identification of high-risk activities. This information enables design teams to identify areas requiring enhancement or modification to ensure safer and more comfortable work postures, therefore mitigating the risk of musculoskeletal disorders [18]. The procedure for evaluating an individual's posture during an activity utilizing the RULA approach, together with the categorization of required tasks, is illustrated in the flowchart in Figure 1 and Table 1.

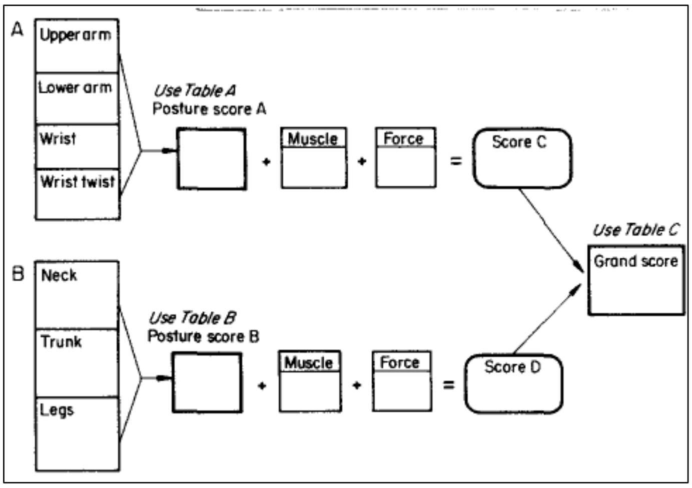

Figure 1. RULA scoring sheet

Table 1. Action Level

RULA Score	Action Level	Action Required
1-2	Low	Safe
3-4	Medium	Action required in the near future
5-6	High	Action required soon
7	Very High	Immediate action required

METHOD

This study examined the driver's posture in the FT UNP prototype car during operation to evaluate the danger level of musculoskeletal disorders. The Rapid Upper Limb Assessment (RULA) approach was selected because to its unique focus on assessing the posture of the upper body, including the arms, neck, back, and wrists, which are the principal body parts involved in vehicle operation. RULA is particularly pertinent for work environments characterized by extended static postures, exemplified by the seated position of drivers in energy-efficient automobiles. In contrast to the REBA approach, which is more suited for dynamic exercises engaging the full body, RULA is more applicable to activities centered on the upper body. Numerous investigations in Indonesia have effectively utilized this strategy for vehicle operators, including electric car drivers and online motorbike taxi drivers, resulting in credible evaluations and offering sensible ergonomic suggestions.

Data Collection

Data collection was carried out through two main approaches:

1. Observation

Data was collected through direct observation, where quantitative data was recorded. Quantitative data refers to measurable and analyzable numerical information, obtained directly from observations of the driver’s condition and the prototype vehicle. The data used in this study includes the driver’s anthropometric measurements and the angles of the driver’s body parts while in the driving position.

2. Literature Review

This stage was conducted to supplement the data collected through literature research and consultations with experts in the relevant fields. The literature review was used to strengthen the research framework and validate the findings.

Data Processing

In the data processing stage, several steps were carried out, as shown in Figure 2.

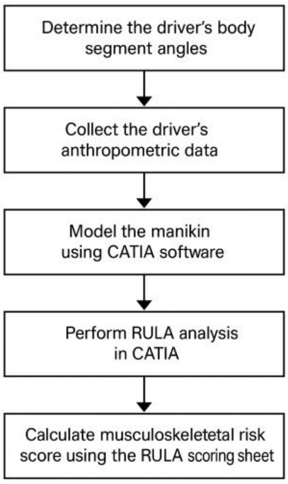

Figure 2. Data collection steps

The detailed steps in the data processing are as follows:

1. Assessing the Angles of the Driver's Anatomical Segments
   The first phase entails ascertaining the primary body angles of the driver in the driving position. The measured angles encompass the upper arm, lower arm, wrist, neck, back, and lower legs. This measurement is conducted to guarantee that the driver's working posture can be precisely modeled in the subsequent phase.

2. Gathering the Driver's Anthropometric Information
   Subsequent to ascertaining the posture angles, the driver's anthropometric data is gathered. This data encompasses body dimensions including height, leg length, arm length, and additional pertinent measurements. The objective of gathering this anthropometric data is to develop a digital mannequin model that precisely represents the driver's physical attributes.
3. Creating the Mannequin with CATIA Software
   The anthropometric data and body posture information are then used to construct a virtual mannequin model using the Human Builder feature in CATIA software. In this stage, the mannequin is adjusted to the driver's seating position based on various cockpit configuration variations, such as seatback angle, steering wheel position, and pedal placement.
4. RULA Assessment in CATIA Software
   Upon positioning the mannequin appropriately, a posture study is performed utilizing the Human Posture study function in CATIA. The software autonomously assesses each body segment and allocates an initial score according to the RULA approach.
5. Determining Musculoskeletal Risk Score Utilizing RULA Assessment Tool
   The posture score obtained from the analysis in CATIA is then verified by recalculating the score manually using the RULA scoring sheet. This step ensures that the driver's posture assessment generated by the software aligns with the standard RULA procedure and is free from systematic errors. By comparing the automatic results from CATIA with the manual calculation, the validity and accuracy of the posture analysis can be confirmed before it is used as the basis for ergonomic decision-making.

RESULT AND DISCUSSION

Driver's Body Angles

The initial step in this simulation was to determine the angles of the driver's body parts using AutoCAD software. These angles were determined by observing the driver's posture while seated in the cockpit of the prototype vehicle. Figure 3 shows the body angle positions of the driver during the driving process.

Figure 3. Driver's Body Angles

Driver's Anthropometric Data

This study involved observations to acquire the driver's anthropometric measures. This data will serve as the foundation for establishing the mannequin size in the ergonomic simulation conducted with CATIA software. The data was obtained immediately through a roll meter. The subsequent table displays the driver's body measures acquired during the observation, as illustrated in Figure 3 and Table 2.

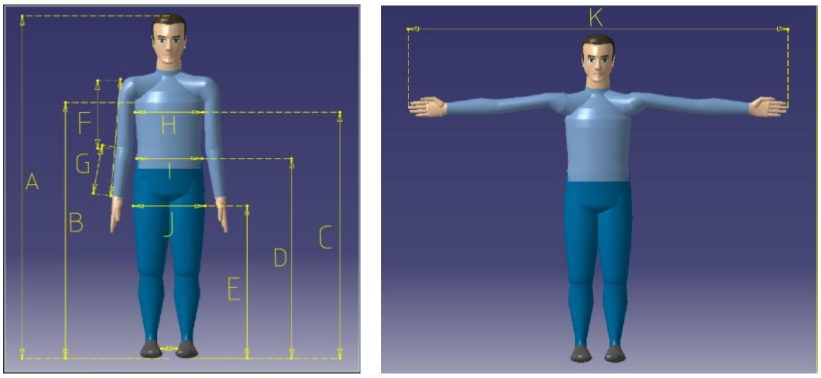

Figure 4. Driver's Anthropometric CAD Data Representation

Table 2. Driver's Anthropometric Data

Symbol	Description	Dimension (cm)
A	Total height from head to feet	154
B	Axilla height (armpit)	116
C	Chest height	114
D	Waist height	87
E	Groin height (inguinal)	68
F	Upper arm length	31
G	Lower arm length	24
H	Chest width	27
I	Waist width	26
J	Thigh width	30
K	Wingspan	163

Mannequin Modeling

Subsequent to acquiring the angular data for each anatomical segment, the following stage involved modifying the mannequin's posture within CATIA software. This modification was implemented to guarantee that the mannequin's posture precisely reflected the actual body position of the driver in the prototype car. Consequently, the ergonomic analysis could be performed with precision. Figure 4 illustrates the mannequin's posture modified to align with the driver's body angles, as detailed in Table 3.

Table 3. Driver's Body Angles

Body Part	Posture Angle (°)
Neck	50°
Trunk	0°
Upper arm	14°
Lower arm	60°
Wrist	0°
Wrist bent	23°
Wrist twist	0°
Legs	18°

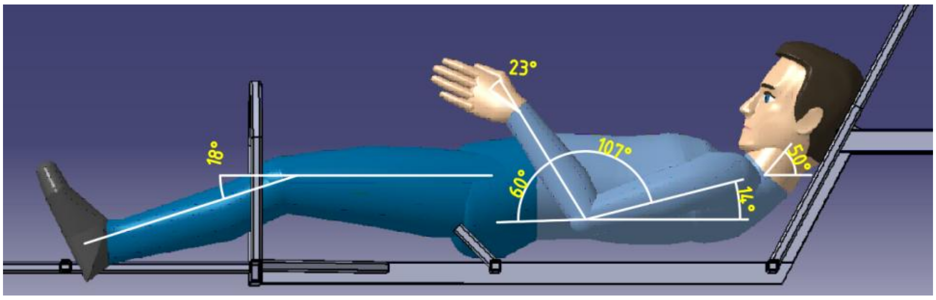

Figure 5. Mannequin limb angles

RULA Simulation Results in CATIA

The simulation results of the driver's posture in the cockpit of the FT UNP prototype vehicle can be seen in Figure 6.

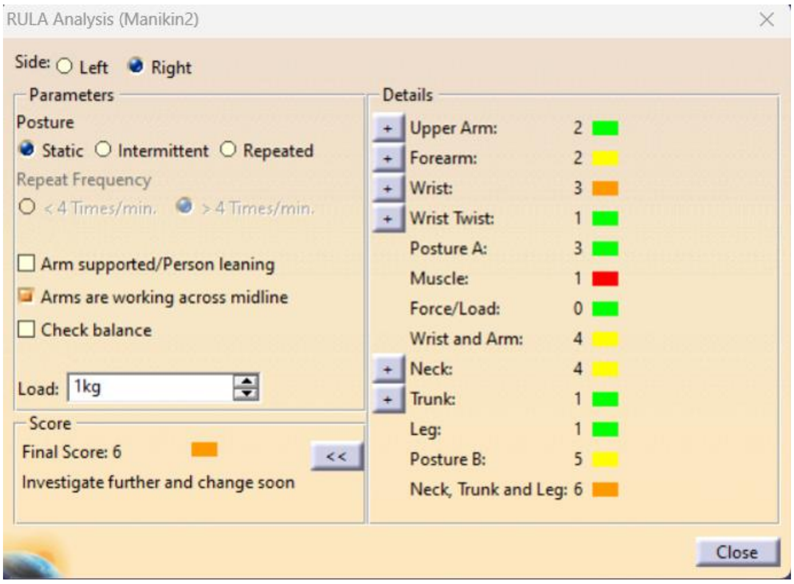

Figure 6. RULA score using CATIA

Analysis of the RULA Scoring Sheet

The following steps can be followed to calculate the simulation results shown in Figure 6:

1. Posture Score A Calculation

   The process for determining Posture Score A using Table 5 is based on the assessment from Table 4.

Table 4. Scoring Posture A

Body Part	Angle (°)	Score	Description	Final Score
Upper arm	14°	1	Raised position while turning the steering wheel +1	2
Lower arm	73°	1	Crossing the body's midline during a turn +1	2
Wrist	5°	2	Bent away from the midline +1	3
Wrist Twist	0°	1		1

Table 5. Posture score A

Table A		Wrist Score							
		1		2		3		4	
Upper Arm	Lower Arm	Wrist Twist		Wrist Twist		Wrist Twist		Wrist Twist	
		1	2	1	2	1	2	1	2
1	1	1	2	2	2	2	3	3	3
	2	2	2	2	2	3	3	3	3
	3	2	3	3	3	3	3	4	4
2	1	2	3	3	3	3	4	4	4
	2	3	3	3	3	3	4	4	4
	3	3	4	4	4	4	4	5	5
3	1	3	3	4	4	4	4	5	5
	2	3	4	4	4	4	4	5	5
	3	4	4	4	4	4	5	5	5
4	1	4	4	4	4	4	5	5	5
	2	4	4	4	4	4	5	5	5
	3	4	4	4	5	5	5	6	6
5	1	5	5	5	5	5	6	6	7
	2	5	6	6	6	6	7	7	7
	3	6	6	6	7	7	7	7	8
6	1	7	7	7	7	7	8	8	9
	2	8	8	8	8	8	9	9	9
	3	9	9	9	9	9	9	9	9

Based on the assessment from Table 5, it can be concluded that with an upper arm score of 2, a lower arm score of 2, a wrist score of 3, and a wrist twist score of 1, the Posture A score is 3.

2. Posture Score B Calculation

The process for determining Posture Score B using Table B follows the steps outlined in Figure 1 and is based on the assessment from Table 6.

Table 6. Scoring Posture B

Body Part	Angle (˚)	Score	Description	Final Score
Neck	50˚	3	Twisted position when turning the head +1	4
Trunk	0˚	1		1
Legs	18˚	1		1

According to the assessment in Table 7, the score for the neck is 4, the trunk is 1, and the legs are 1, resulting in a total Posture B score of 5.

3. Posture Score C Calculation

The subsequent stage is to ascertain the muscle and force values necessary to derive the final Posture Score C. The final Posture Score C is derived by aggregating the Posture A score, muscle, and force variables as illustrated in Figure 1. The muscle value attributed to Driver 1 during the driving procedure is +1 due to the position being largely static for over one minute. The force value allocated to Driver 1 throughout the driving process is +0, as it is presumed that the load exerted when operating the prototype vehicle is under 1 kg. Consequently, the ultimate Posture Score C is computed as follows:

Posture Score C = Posture Score A + muscle + force
Posture Score C = 3 + 1 + 0
Posture Score C = 4

By summing the Posture A score and the muscle and force values, the final Posture Score C is 4.

Table 7. Posture score B

Neck Posture Score	Trunk Posture Score											
	1		2		3		4		5		6	
	Legs		Legs		Legs		Legs		Legs		Legs	
	1	2	1	2	1	2	1	2	1	2	1	2
1	1	3	2	3	3	4	5	5	6	6	7	7
2	2	3	2	3	4	5	5	5	6	7	7	7
3	3	3	3	4	4	5	5	6	6	7	7	7
4	5	5	5	6	6	7	7	7	7	7	8	8
5	7	7	7	7	7	8	8	8	8	8	8	8
6	8	8	8	8	8	8	8	9	9	9	9	9

4. Posture Score D Calculation

The subsequent stage involves ascertaining the muscle and force values necessary to derive the final Posture Score D. The ultimate Posture Score D is derived by aggregating the Posture B score, muscle, and force variables as seen in Figure 1. The muscle value attributed to Driver 1 during the driving procedure is +1 due to the position being largely static for over one minute. The force value designated to Driver 1 during the driving process is +0, as it is presumed that the weight exerted when operating the prototype vehicle is below 1 kg. Consequently, the ultimate Posture Score D is computed as follows:

Posture Score D = Posture Score B + muscle + force
Posture Score D = 5 + 1 + 0
Posture Score D = 6

By summing the Posture B score with the muscle and force values, the final Posture Score D is 6.

5. Grand Score

The final step is to determine the RULA grand score using Table C, based on the previously obtained Posture Score C and Posture Score D. This process follows the steps outlined in Figure 1. The process for determining the RULA grand score using Table C is shown in Table 8.

Table 8. Grand score

Table C		Neck, Trunk, Legs Score						
		1	2	3	4	5	6	7+
Wrist/Arm Score	1	1	2	3	3	4	5	5
	2	2	2	3	4	4	5	5
	3	3	3	3	4	4	5	6
	4	3	3	3	4	5	6	6
	5	4	4	4	5	6	7	7
	6	4	4	5	6	6	7	7
	7	5	5	6	6	7	7	7
	8+	5	5	6	7	7	7	7

Table 8 shows that the Posture Score C obtained is 4, and the Posture Score D is 6, resulting in a calculated RULA score of 6. This value falls into the high category, indicating the need for immediate assessment and changes.

CONCLUSION

The evaluation of the driver's working posture in the FT UNP prototype car, utilizing the RULA approach, yielded a musculoskeletal risk score of 6, categorizing it as high risk. Consequently, additional examination and modification of the cockpit design are essential to enhance the driver's posture and mitigate the risk of damage.

Subsequent to the investigation and deliberation, some recommendations are put forth: Future research should investigate ergonomic seat designs customized to the driver's physique to improve comfort in the prototype car. Secondly, it would be advantageous for future study to administer a follow-up questionnaire post-implementation of the proposed posture enhancement solutions to assess the driver's reaction to the reconfigured cockpit.

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