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Enhancing Army Vehicle Ingress-Egress Safety: A Comprehensive Analysis of Ergonomics using Digital Human Modeling and Rapid Upper Limb Assessment

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***Abstract*—This This research focuses on assessment of the ingress-egress process for the crew cabin of an Indian army vehicle using a digital human modeling and simulation technique within a virtual computer-aided design environment. The primary aim is to thoroughly investigate the factors that influence army vehicles' entry and exit procedures, ultimately enhancing the safety, comfort, and overall performance of military personnel. By leveraging the advantages of a virtual environment, simulations are conducted to accurately replicate the complexities of army vehicle ingress-egress, eliminating the need for human involvement. The Rapid Upper Limb Assessment (RULA) tool is employed to evaluate and quantify the potential ergonomic risks and challenges associated with these activities, mainly focusing on the musculoskeletal strain levels and discomfort experienced by individuals. The findings improve our understanding of army vehicle ergonomics and help optimize and improve ingress-egress mechanisms for soldiers in routine and emergency combat situations.**

***Keywords*—Digital Manufacturing, Digital Human Modeling, Musculoskeletal Disorders, Digital Mock-Up, RULA .**

1. INTRODUCTION

The success of automotive products greatly relies on incorporating ergonomic design features that prioritize the safety and comfort of drivers, conductors, and passengers. Among various design considerations, the provision of proper entry-exit facilities is of paramount importance in ensuring optimal vehicle design. Inadequate entry-exit mechanisms can lead to frequent injuries, as evidenced by reported incidents involving truck drivers experiencing slips and falls [1 - 3]. Entry-exit facilities in vehicles should be designed to accommodate users of diverse anthropometry, age, sex, physical limitations, and normal-emergency situations with minimal mechanical adjustments. Designing a facility that is compatible with all individuals poses challenges, which are further compounded when dealing with army vehicles with specific operational requirements.

In a country like India, where there is a significant anthropometric variation among army personnel [13], it becomes essential to consider ethnic variations and percentile distribution within the Indian army population when developing or procuring vehicles and equipment for military purposes. In the context of army vehicles, ensuring easy and safe ingress-egress of soldiers, wearing various military ensembles, in normal, emergency, and combat situations is of utmost importance. Traditionally, evaluating entry-exit facilities involves physical mock- ups and real trials with drivers and passengers. However, digital human modeling can significantly facilitate the evaluation process at the early stages of design, even before developing physical mock-ups or initial prototypes. Utilizing digital human modeling allows for the assessment of doors, stairs, and other accessories in a simulated environment, saving time and costs associated with involving individuals of diverse anthropometry in real scenarios [4]. The state-of-the-art approach in facility and workstation design involves digital modeling and simulations, enabling the assessment of virtual vehicle prototypes using digital human modeling (DHM) for ergonomic considerations. DHM programs utilize computer-aided design (CAD) software's to create accurate computer graphics environments [4, 5]. In this study, we utilize DHM and simulation with CATIA (computer aided three-dimensional interactive application) software to evaluate the ingress-egress process in the crew cabin of an army vehicle, effectively assessing entry-exit facilities without real human involvement. The research showcases the potential of digital human modeling and simulation to enhance army vehicle design, emphasizing the importance of improved entry-exit mechanisms for soldier safety and operational efficiency. The findings provide valuable insights for designers, engineers, and stakeholders involved in army vehicle development, contributing to the field of ergonomics and human factors in vehicle design.

The emerging tools of DHM and virtual ergonomics have the potential to revolutionize ergonomics analysis by transforming the design process, conducting ergonomic evaluations, and assessing disorders or impairments. However, traditional physical mock-up methods still persist for workplace analysis, highlighting the importance of designing functional and ergonomically acceptable production workstations. By employing DHM during the initial phases of product development and design, essential ergonomic factors can be integrated, resulting in the elimination of physical prototypes and a decrease in post-design modifications and their related expenses. Furthermore, various ergonomic

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assessment tools are available to measure the ergonomic risk of work or tasks, allowing for early intervention and improved workplace ergonomics [6, 16].

In a study conducted by Occhipinti (1998), the Occupational Repetitive Action Approach (OCRA) was utilized to evaluate the risk of work-related musculoskeletal disorders (WMSDs) in the upper extremities of workers [7]. This analytical tool is widely regarded as a highly effective method for evaluating workplace ergonomics. To estimate the risk of WMSDs issues in the upper limbs, the Strain Index is used to determine the strain exerted on the body and muscles [8]. In their study, David Geoffrey et al. (1995) utilized the Quick Exposure Check (QEC) approach to objectively evaluate and validate the analysis of physical observations [9]. McAtamney and Corlett (1993) presented the RULA assessment approach to examine the ergonomics of the human body [10]. Observational methods in ergonomics have been assessed and found suitable for various workplace scenarios, but differences in postural scores can arise due to unique categorization procedures. The RULA is a widely used subjective observation method that provides a prominent technique for evaluating the ergonomic risk of WMSDs. The RULA assessment score, divided into four action levels indicating severity, offers advantages such as quick evaluation, correlation with pain, objective intervention measurements, accuracy and reliability, and time-saving digital implementation [11]. The RULA assessment scores and MSDs risk levels has been shown with Table 1.

Table 1. RULA assessment scores and MSDs risk levels

RULA Assessment Score	MSDs risk levels
1 to 2	Negligible risk, no action
3 to 4	Low risk, change may be
5 to 6	Medium risk, further
6 +	Very high risk, implement change now

The current paper is organized as section 1 includes existing practices with comprehensive literature findings. Section 2 depicts methodology adopted for RULA assessment. Section 3 is followed by RULA assessment scores for Ingress and Egress process on the army vehicle. Section 4 describes result and discussion with Digital mock-up reviews observations for human ergonomics assessment, Section 5 includes the conclusive remarks.

2. METHODOLOGY OF RULA ASSESSMENT

The investigation of army vehicle ingress-egress ergonomics using the RULA assessment tool followed a systematic approach with defined steps. CATIA Software Human Activity Analysis workbench utilized to conduct the assessment and analyze soldier's digital manikin postures. The focus was on studying the process of climbing into and getting down from an army truck to assess upper limb disorder risks. Human manikins representing army personnel's anthropometric variation were used. The RULA assessment procedure using CATIA Software is illustrated in Figure 1.

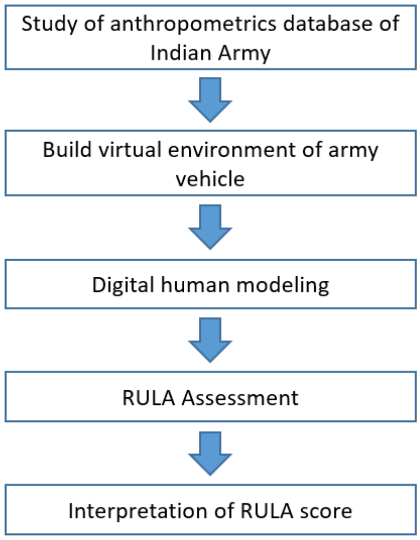

Fig 1. RULA Assessment methodology utilizing CATIA software

2.1. Study of anthropometrics database of Indian army

The research utilized an anthropometric database of 11,458 individuals from the Indian army population to evaluate the entry-exit requirements of soldiers [12]. The Gorakha and Sikh-Punjabi soldier's groups, representing the smallest and largest body dimensions respectively, were identified as extreme populations in Indian army [12]. Digital human models were generated based on the 5th percentile Gorkha (5th p G) and 95th percentile Sikh-Punjabis (95th p SP), representing the shortest and largest individuals within the army population for research purpose. The 50th percentile army personnel (50th p AP) soldier was chosen as the representative of the average soldiers across the entire army population although it is acknowledged that not all body dimensions align with the same percentile category [13].

2.2. Virtual environment of army vehicle for DMU.

The advanced digital manufacturing features of CATIA enable the translation of real-world dimensions of the army vehicle into a comprehensive virtual three-dimensional (3D) model. By creating a digital CAD model in CATIA, including accurate dimensions and specifications of the vehicle, along with all necessary components, the physical vehicle environment is studied, and measurements are taken to transform the dimensions into a 3D model. This virtual model is then used for conducting DMU packaging studies and performing Virtual Ergonomics analysis to assess the ingress-egress of the existing army vehicle. By incorporating virtual prototyping during the initial phases of product development and design, the requirement for physical prototypes is eliminated. Figure 2, depicts the virtual 3D model of an army vehicle created using CATIA software.

Fig 2. Army vehicle 3D CAD model in virtual environment for DMU review

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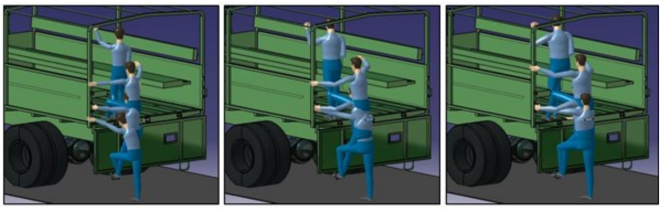
2.3. Utilizing Digital Human Modeling for Army Personnel

The CATIA Human Builder workbench is utilized to select digital manikins representing soldiers of different percentiles from the database [12]. The selected manikins' body postures are adjusted using the Human Builder tool to replicate real-time movements during army vehicle ingress-egress. These modified manikins are then used for RULA analysis, considering specific postures and different conditions, including load-bearing scenarios [14]. Figure 3, depicts the body postures of soldier digital manikins of different percentiles representing ingress-egress process on the army vehicle.



(a) 5th percentile Gorkha manikin (b) 50th percentile Army personnel (c) 95th percentile Sikh-Punjabis

Fig 3. Army population different percentile manikins to analyze Ingress-Egress on vehicle.

2.4. RULA Assessment

The RULA assessment analyzes the working postures of digital manikins representing different army soldier percentiles to assess the risk of MSDs during ingress-egress on army vehicles. The assessment is performed in a virtual environment using CATIA software's Human Posture Analysis workbench, allowing for the selection of body segments, load simulation, and defining posture movement nature. Table 1, presents a comprehensive overview of the ergonomic risks linked to musculoskeletal disorders (MSDs) and provides recommended actions for risk mitigation. Furthermore, Figure 2 showcases the scores assigned to different body segments, accompanied by corresponding color schemes indicating the respective levels of ergonomic risk.

Table 2. CATIA software RULA assessment: body segment scores and color scheme

Body Segments	Score Range	Color associated with score								
		1	2	3	4	5	6	7	8	9
Upper Arm	1 to 6	✓	✓	✓	✓	✓	✓			
Forearm	1 to 3	✓	✓	✓						
Wrist	1 to 4	✓	✓	✓	✓					
Wrist Twist	1 to 2	✓	✓							
Posture A	1 to 9+	✓	✓	✓	✓	✓	✓	✓	✓	✓
Muscle	0 to 1	✓								
Force/Load	1 to 3	✓	✓	✓						
Wrist and Arm	1 to 8+	✓	✓	✓	✓	✓	✓	✓	✓	✓
Neck	1 to 6	✓	✓	✓	✓	✓	✓			
Trunk	1 to 6	✓	✓	✓	✓	✓	✓			
Leg	1 to 2	✓	✓							
Posture B	1 to 9+	✓	✓	✓	✓	✓	✓	✓	✓	✓
Neck, Trunk and Leg	1 to 9	✓	✓	✓	✓	✓	✓	✓	✓	✓
RULA assessment score	1 to 6+	✓	✓	✓	✓	✓	✓	✓	✓	✓

This study segmented the ingress-egress activity into three steps and employed three distinct manikins representing different percentiles [15]. There is a total of 12 specific ingress-egress or climbing and getting down activities tailored to different percentile army populations to conduct RULA assessment in virtual environment. Each army percentile configuration is divided into three posture steps A, B and C,resulting in a total of 36 body postures for

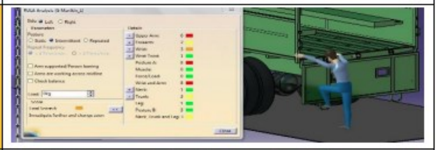
Ingress postures	RULA scores	Assessment image
A	6	
B	4	
C	3	
RULA assessment score		6

Fig 4. 5th percentile (5th p G) manikin ingress on army vehicle with no body carriage load

Ingress postures	RULA scores	Assessment image
A	7	
B	7	
C	7	
RULA assessment score		7

Fig 5. 95th percentile (95th p SP) manikin ingress on army vehicle with body carriage load

Table 3. RULA assessment scores for Ingress process on the army vehicle.

Load conditions	With no body carriage load									With body carriage load								
Manikin percentiles	5th p G			50th p AP			95th p SP			5th p G			50th p AP			95th p SP		
Ingress postures	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Upper arm	6	5	4	6	4	4	5	5	5	6	5	4	6	4	4	5	5	5
Forearm	2	2	2	2	2	3	2	3	2	2	2	2	2	2	3	2	3	2
Wrist	3	3	2	2	2	3	3	4	3	3	3	2	2	2	3	3	4	3
Wrist twist	1	1	1	1	1	1	1	1	1	1	1	4	1	1	1	1	1	1
Posture A	8	6	4	8	4	5	6	7	6	8	6	1	8	4	5	6	7	6
Muscle	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Force/load	0	0	0	0	0	0	0	0	0	2	2	2	2	2	2	2	2	2
Wrist and Arm	8	6	4	8	4	5	6	7	6	10	8	6	10	6	7	8	9	8
Neck	1	1	1	1	4	1	1	1	1	1	1	1	1	4	1	1	1	1
Trunk	3	2	2	2	3	2	2	2	2	3	2	2	2	3	2	2	2	2
Leg	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Posture B	3	2	2	2	6	2	2	2	2	3	2	2	2	6	2	2	2	2
Neck, Trunk and Leg	3	2	2	2	6	2	2	2	2	5	4	4	4	8	4	4	4	4
RULA analysis Score	6	4	3	5	6	4	4	5	4	7	7	6	7	7	6	7	7	7

evaluating RULA scores for human ergonomics assessment. The highest RULA score obtained among the various ingress-egress step postures for a specific army percentile are considered as the final RULA score for the assessment. The Figure 4 and 5 represent the RULA assessment scores of Ingress 5th percentile (5th p G) without body carriage load and

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95th percentile (95th p SP) with body carriage load in simulated environment. The Table 3 and 4 represent the RULA Assessment scores for ingress-egress process on the army vehicle for all three soldiers' digital manikins.

Table 4. RULA assessment scores for Egress process on the army vehicle.

Load conditions	With no body carriage load									With body carriage load								
Manikin percentiles	5th p G			50th p AP			95th p SP			5th p G			50th p AP			95th p SP		
Egress postures	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Upper arm	4	5	6	4	4	6	5	5	5	4	5	6	4	4	6	5	5	5
Forearm	2	2	2	3	2	2	2	3	2	2	2	2	3	2	2	2	3	2
Wrist	2	3	3	3	2	2	3	4	3	2	3	3	3	2	2	3	4	3
Wrist twist	1	1	1	1	1	1	1	1	1	4	1	1	1	1	1	1	1	1
Posture A	4	6	8	5	4	8	6	7	6	1	6	8	5	4	8	6	7	6
Muscle	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Force/load	0	0	0	0	0	0	0	0	0	2	2	2	2	2	2	2	2	2
Wrist and Arm	4	6	8	5	4	8	6	7	6	6	8	10	7	6	10	8	9	8
Neck	1	1	1	1	4	1	1	1	1	1	1	1	1	4	1	1	1	1
Trunk	2	2	3	2	3	2	2	2	2	2	2	3	2	3	2	2	2	2
Leg	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Posture B	2	2	3	2	6	2	2	2	2	2	2	3	2	6	2	2	2	2
Neck, Trunk and Leg	2	2	3	2	6	2	2	2	2	4	4	5	4	8	4	4	4	4
RULA analysis score	3	4	6	4	6	5	4	5	4	6	7	7	6	7	7	7	7	7

3. RESULTS AND OBSERVATIONS

3.1. Results

The RULA assessment evaluated the ingress-egress process of army vehicles, focusing on upper limb disorder risk. Table 5 summarizes the RULA assessment scores for various ingress-egress body postures, highlighting the final RULA score to determine the ergonomic risk for musculoskeletal disorders. By observing the body segments of manikins in Tables 3 and 4, it is evident that poor reachability and a lack of hand-holding aids contribute to muscle strain in the upper arm, wrist, and wrist twist segments. The RULA assessment final scores indicate a moderate to high ergonomic risk in ingress and egress activities for different army populations.

Table 5. Summary of RULA assessment scores for ingress-egress process on the army vehicle.

Activity	Indian army population	RULA Assessment Score	
		With no body carriage load	With body carriage load
Ingress	5th p G - Gorkha	6	7
	50th p AP - Army Personnel	6	7
	95th p SP - Sikh-Punjabis	5	7
Egress	5th p G - Gorkha	6	7
	50th p AP - Army Personnel	6	7
	95th p SP - Sikh-Punjabis	5	7

3.2. Digital mock-up reviews observations for human ergonomics assessment

The observation findings highlight significant challenges and safety risks associated with climbing and getting down from army vehicles.

1) The absence of a standardized climbing and getting down structure on army vehicles hampers safe and comfortable entry and exit operations.
2) The height difference between the ground and the vehicle floor is significant, accounting for approximately three-quarters of a soldier's body height. To ascend the vehicle, army personnel rely on climbing protrusion rods, tailgate steps, grab handles on the load body, and wire ropes. However, these methods increase the risk of falls from heights.
3) The accessibility of grab handles, hand-holding ropes, and climbing protrusion rods is inadequate, forcing soldiers to extend their bodies to reach them. Additionally, there are uneven gaps between the climbing supports, protrusion rods, and the floor. Furthermore, there is limited visibility of the protrusion rods and climbing protrusion steps during the descent process.
4) The current process of climbing and getting down from army trucks is time-consuming, and during emergencies, soldiers may be forced to jump out of the vehicle, elevating the risk of injuries.
5) The presence of military ensembles further complicates the climbing and getting down process, making it particularly challenging for soldiers in emergency conditions.

4. DISCUSSION

Recognizing the importance of human factors in vehicle design, particularly ingress-egress, from the initial stages is crucial to prevent user dissatisfaction and costly modifications in the future. By acknowledging the risks identified through the RULA assessment, the incorporation of standardized climbing footstep structures and hand-holding aids can significantly enhance the ergonomics and safety of the army vehicle ingress-egress process.

The RULA assessment scores reveal a high MSDs risk in the current army vehicle ingress-egress process, underscoring the need for significant design changes. The analysis identifies concerns like muscle strain in upper arm and wrist segments, emphasizing the importance of addressing reachability and hand-holding aids in the vehicle's design to enhance soldier safety and comfort during entry and exit, in normal and emergency situations. The research study demonstrates the valuable benefits of using digital human modelling and simulation to study vehicle ingress-egress. This approach enables design engineers to enhance vehicles, save time and costs, and reduce errors and accidents, a similar viewpoint is expressed by Bowman (2001), who suggests that digital human modelling holds potential in ensuring the physical comfort and stability of the driver during the ingressegress process in vehicle cabins [16].

The virtual case study on army vehicle ingress-egress highlights the effectiveness of digital human modeling tools in replacing expensive physical mockups for evaluating human-centric design criteria. This approach proves to be a cost-efficient alternative to traditional methods that involve time-consuming human trials, Chaffin (2005) have also acknowledged that digital human modelling software offers a more effective and cost efficient approach for design and evaluation compared to traditional cardboard modelling and mock-ups [17]. The application of digital human modelling and simulation for driver ingress analysis in passenger cars and light heavy trucks is well-established in many countries. However, the utilization of RULA assessment for human ergonomics analysis in vehicle, product, and workplace design is a novel approach in context of India [18].

5. CONCLUSION

The RULA assessment scores obtained from the study offer significant insights into the musculoskeletal disorder risk level associated with the army vehicle ingress-egress process. The results highlight specific areas of concern that require attention to mitigate ergonomic challenges and minimize the risk of musculoskeletal disorders among army personnel. The identified need for design changes underscores the importance of addressing the observed limitations and deficiencies in the current vehicle entry and exit mechanisms. By implementing the recommended improvements based on the assessment findings, it is possible to enhance the safety and comfort of soldiers during ingress and egress activities. This, in turn, can have a positive impact on their overall performance, operational efficiency, and safety in case of normal use and emergencies. The study emphasizes the significance of prioritizing ergonomics in army vehicle design to ensure optimal working conditions and reduce the potential for work-related injuries and musculoskeletal discomfort.

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