

Optimizing Operator Ergonomics to Increase National Agricultural Productivity and Work Comfort by 2027

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Abstract

Operating a hand tractor (HT) in rice fields requires a physical and mental workload, including maneuvering, sitting positions, and muddy terrain conditions, which have not been addressed by anthropometric variations in HT (OHT) operators. This study aims to analyze the psychophysiological and postural burden on OHT operators based on variations in working time. The study used a Pseudo-Holistic Ergonomics Experiment (PHEE) on 30 OHTs in three rice fields (Kediri, Tulungagung, and Trenggalek) in East Java, Indonesia. Five 30-minute time variations, spanning six days, were evaluated using Heart Rate (HR), Internal Ratio of Heart Rate (IRHR), and Cardiovascular Load (CVL), Rapid Upper Limb Assessment (RULA), and Rapid Entire Body Assessment (REBA). Anthropometric variations were used to determine percentiles (5th, 50th, and 95th). Bilateral RULA score 5.47 ± 0.73 , range 5–7; 86.67% of the assessment score 5–6; 13.33% score 7. REBA reached 8.70 ± 1.64 on the left side; 8.77 ± 1.72 on the right side, with 70.00% at high risk, 16.67% at very high risk. DNK increased from 86.13 ± 3.80 beats/minute at 06.00 to 99.80 ± 1.03 beats/minute at 15.00, then decreased to 75.73 ± 3.82 beats/minute at 17.00. The difference in DNK between times was significant ($F(2,742;79,520) = 369.532$; $p < 0.001$), while CVL was kept positive with age ($r = 0.591$; $p < 0.001$). IRHR was significantly attenuated by CVL ($r = 0.876$; $p < 0.001$). The height of OHT workers ranges from 153–167 cm, with $P5 = 153.37$ cm, $P50 = 160.56$ cm, and $P95 = 167.75$ cm. OHT workers experience high physiological loads with significant temporal variations, from midday to evening work periods. The findings support the implementation of EDDs to adapt saddle height, handlebar distance, and grip angle to anthropometric variations, as well as policies for establishing work-related rest schedules to reduce the risk of MSDs and ensure the continued safety of OHT workers.

Key words: anthropometric; cardiovascular load; handlebar distance; mental workload; operating a hand tractor.

1. Introduction

Extreme weather causes crop failure with a risk of 3.92 times resilience and 3.48 times depression, where a survey of 206 farmers, 79% considered flooding as the main threat (Howse, Rose, Watson, Maye, & Morgans, 2026; Labayo & Pre, 2026; Sepúlveda et al., 2026; Sperstad, Skjerve, Coleman, Muri, & Torske, 2026; Tambadou et al., 2025), depending on Hand Tractor (HT) for small-medium scale rice fields (Karimi & Mann, 2008; Kuta, Stopa, Szyjewicz, & Komarnicki, 2019; Liu, Lü, Zheng, Zhang, & Cheng, 2019; Sepúlveda et al., 2026). Farmers' burdens include weather conditions (2.6%), future concerns (9.8%), financial income (17.0%), operational costs (5.9%), and physical and mental health (KSM) (Schaffler, Fazekas, Neubauer, & Humer, 2026). The need for efficiency, especially KSM, to increase the safety and productivity of farmers, especially HT (OHT) operators as a modernization of agricultural equipment (G. An et al., 2024; Karimi & Mann, 2008; Wang et al., 2022; Xu et al., 2023). HT improves plowing, but the manual turning clutch is burdensome due to unbalanced hand reach (JT) when maneuvering muddy ground (Y. An, Wang, Deng, Chen, & Lu, 2023; C. Y. Id, Id, Gao, & Li, 2023; Jia, Smith, Peng, Robotics, & Arbor, 2012; Szabo, Doba, & Aradi, 2024; Zhang et al., 2025)(Fig. 1).



Figure 1. (a) OHT Load Factor; (b) OHT Working Conditions
Source: (Dhafir & Ja, 2022; Schaffler et al., 2026; Tani, 2021)

Kediri is famous for its rice production of 191805.33 tons (2023), 182,465.1 tons (2024) due to its dominant rice field area. However, the psychological workload of OHT is affected by large muddy fields, weather 38–40°C causing high-risk complaints of cardiovascular (CVL) 19.8%, incorrect work posture, fatigue 20.4%, Musculoskeletal Disorders (MSDs) 28.5%, total energy consumption (TEC) 14.67 kcal/minute, pulse rate reaching 81.4 times/minute, indicating excessive biomechanical stress during plowing the rice fields (Bara, Juri, & Juri, 2025; Dhafir & Ja, 2022; Houshyar & Kim, 2018; Humer et al., 2026; Malonda, Kawatu, & Doda, 2016; Pradana, 2021; Sperstad et al., 2026; Wahyun, Raharja, Rohmatin, & Areza, 2024; Wilhelmsson et al., 2021; Yusuf, Adiputra, Sutjana, & Tirtayasa, 2016).

Initial survey, extreme fatigue is triggered by the interaction of dry land and muddy ground and non-ergonomic posture, the average height of OHT is 155 cm, making the handlebars unreachable by the hands and the saddle seat monotonous (Dong, Li, Fu, & Wang, 2022; Uday, Krishna Prasad, Govindasamy, Krishnasamy, & Raju, 2020). Critical condition of HT turning maneuver, Energy 2.09; *Internal Ratio of Heart Rate* (IRHR) 1.5; oxygen requirement (VO_2) 219 accelerate fatigue (Bispo, Moreno, Silva, Albuquerque, & Silva, 2022; Hutabarat, Achmadi, Alfian Pradana, & Wilis Lestarinig Basuki, 2024; Kusmawan, Izhar, & Aswin, 2024).

MSDs study of 68.3% high workload, 19.8% CVL; 81.4 beats/minute (Yang, Sheng, Chen, Zhu, & Yue, 2025); VO_2 78.9 ml/kg/minute; energy 14.67 kcal/minute; and

metabolism 1585.68 kcal/hour, heavy mechanical (traditional) force during HT use(Pradana, 2021),(Singh et al., 2024). Difficulty level up to 70% on barren land (Favennec, Frère, & Mornieux, 2024). The intervention only reduced back muscle injuries by 24%, productivity increased by 17% (Emami, Dehghanisani, & Hajimirzajan, 2024),(Ray, Santra, Mishra, & Das, 2023),(Makar, Al-Hemoud, Khraishah, Berry, & Alahmad, 2024),(Zhu et al., 2025). Need for HT repair, reduce mental burden during working hours (Watanabe & Sakai, 2023), the load on the ligaments and SC increases(Abdous, Delorme, Battini, & Sgarbossa, 2025; Ceccacci, Matteucci, Peruzzini, & Mengoni, 2019; Mazaheri, Neumann, & Trask, 2024; Satapathy, Kumar, Garanayak, & Pani, 2018; Xu et al., 2023). JT steering is not ergonomic, causing back, arm, calorie and finger injuries (Houshyar & Kim, 2018; Pradana, 2021; Wilhelmsson et al., 2021). The weaknesses of previous studies include (1) there is no psychophysiological-biomechanical-cognitive (PBK) integration; (2) the dominance of literature in evaluation, there is no EDD decision; (3) the absence of adaptive SA-anthropometry; (4) there is no time variation in workload in OHT.

The incidence of MSDs, mental-physical-cognitive (MFC) fatigue and maneuvering difficulties increases with increasing working hours and age (Dong et al., 2022; Z. X. Id, Luo, Cao, Niu, & Id, 2024; Man, Bak, Son, Kim, & Jung, 2021; Watanabe & Sakai, 2023). The comfort of the handlebars and saddle of the HT crucially affects work posture and fatigue after 12:00 WIB (Techniques, 2023),(Xu et al., 2023),(G. An et al., 2024). Ligament load increases drastically due to high actuation forces, triggering fatigue of the Pronator Teres (PT) and Radial Wrist Flexor (RWL) muscles (Xu et al., 2023)(Fig. 2). This condition is a psychophysiological impact, where the simultaneous workload increases Heart Rate (HR), decreases HR Variability (HRV), the complexity of plowing the rice fields changes the MFK response, as evidenced by the enlarged pupil diameter in response to mental stress and the body's response (Li et al., 2025; Lisanne, Jonathan, Rainer, & Bernhard, 2024; Nugent et al., 2023; Wiediartini, Ciptomulyono, & Dewi, 2024).

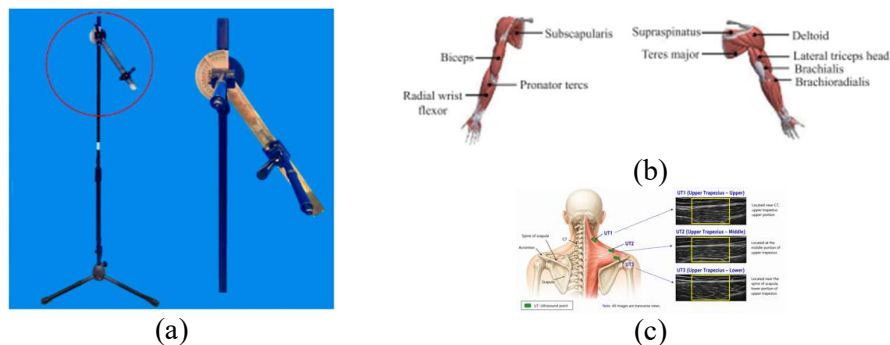


Figure 2.(a) Adoption of the shoulder joint angle; (b) Position indication of each muscle (PIEC); (c) Tense trapezius muscle

Source:(Ciekalski et al., 2024; Tapanya, Neubert, Puntumetakul, & Boucaut, 2021; Xu et al., 2023)

Anthropometric responses to the HT handlebar-saddle distance are not yet available, a new handlebar-saddle design is needed to reduce the psychophysiological dimensions (physiological, cognitive, Cardiovascular Strain (SC), and mental load) of OHT (Techniques, 2023),(Abdous et al., 2025; Ceccacci et al., 2019; Mazaheri et al., 2024;

Satapathy et al., 2018).

Problem solving using Pseudo-Holistic Ergonomics Experiment (PHEE) to address the complexity of OHT workload (Approach, 2026; Peng et al., 2026; Yuan et al., 2025). Stage 1, by mapping the existing conditions of OHT and the rice field environment through physiological, biomechanical and cognitive using HR, spirometer, National Aeronautics and Space Administration Task Load Index (NASA – TLX), Rapid Upper Limb Assessment (RULA), Rapid Entire Body Assessment (REBA) and visual documentation to identify the roots of fatigue, posture risks and operational obstacles in variations in working time (06.00; 09.00; 12.00; 15.00; 17.00 WIB) with a duration of 30 minutes for 6 days. Stage 2, designing HT developed with multi percentile anthropometry (5th, 50th, and 95th) for SA configuration according to JT, grip angle and OHT posture.

This study offers (1) integration of EDD-psychophysiological as a SA blueprint for OHT; (2) developing SA-Anthropometric Multi Level (5th, 50th, and 95th) (SAAML) as an adaptive variation of OHT posture to reduce the risk of specific MSDs; (3) PHEE as a HT design guide.

OHT performance is determined by psychophysiological capacity that is vulnerable to non-adaptive HT, thus increasing MFK-MSDs. This encourages the need to develop ergonomic parameters as a priority for handlebar-saddle design. This study conducted a psychophysiological integrated Ergonomic-Driven Design (EDD) as a strategic solution to optimize the limitations of conventional integrated handlebar-saddle designs in stabilizing OHT performance throughout the day.

This study contributes to the development of integrated adaptive ergonomics PHEE-EDD-SAAML, as a design decision-based OHT risk evaluation considering psychophysiological, biomechanical, cognitive interactions and work time variations to optimize OHT actuation posture-force with posture angle recommendations as a determination of critical work periods and work-rest schedule (WRS).

2. Research methods

2.1. Research Design

The study was conducted using a quantitative PHEE-EDD-SAAML framework in 3 rice field areas in Kediri, Tulungagung and Trenggalek areas of East Java, Indonesia, as a basis for developing recommendations for the design of working angles and hand tractor (HT) configurations.

2.2. Research Population and Sample

The population consists of OHTs actively engaged in agricultural land management activities in three areas. Purposive sampling as an inclusion requirement includes (1) OHTs who have been active for at least two years; (2) those aged 50-65 years; and (3) those who are able to operate HT independently. Exclusion criteria include (1) OHTs who have a history of health conditions and are unwilling to participate in the research process. The number of samples involved is 10 OHTs in each area.

2.3. Research Instruments

The instrument includes variables, dimensions with indicators to produce research (Table 1).

Table 1. Research Instruments

No.	Variables	Dimensions	Indicator	Instrument	Unit
1	Psychophysiological Workload (Y1)	Physiological	Heart Rate (HR)	Heart Rate Monitor	beats/minute
			Internal Ratio of Heart Rate (IRHR)	Heart Rate Monitor; IRHR calculation	Ratio
			Cardiovascular Load (CVL)	HR Monitor; CVL calculation	%
2	Biomechanical Load (Y2)	Posture	RULA Score	RULA	Score 1–7
			REBA Score	REBA	Score 1–15
		Biomechanics	Shoulder position	Visual documentation	Degrees (°)
			Arm position	Visual documentation	Degrees (°)
			Wrist position	Visual documentation	Degrees (°)
			Back position	Visual documentation	Degrees (°)
			Hand reach	Anthropometric measurements and visual documentation	cm
3	Cognitive Load (Y3)	Mental	NASA-TLX	Dimensions: Mental Demand (MD), Physical Demand (PD), Temporal Demand (TD), Performance (P), Effort (E), Frustration (F)	Score 0–100
4	Working Hours (X3)	Temporal variation	Operating time	Experiment schedule	06.00; 09.00; 12.00; 15.00; 17.00 WIB
5	Control Variables	Operator characteristics	Age	Identity questionnaire	Year
			Work experience	Identity questionnaire	Year

Source: processed by researchers (2026)

2.4. Ethical Clearance

This series of studies adhered to ethical principles of research involving humans. Respondents were provided with an explanation of the research objectives, voluntarily, and their identities were kept confidential, for research purposes only.

2.5. Data collection technique

Study with the implementation of existing conditions with identification of research instruments (Table 1). Data collection begins with identifying the characteristics of the OHT, measuring the HT handlebars and saddles (height, distance and grip angle), documenting sample activities to obtain research variable data to produce recommended dimensional designs. The duration of data collection uses time (06.00; 09.00; 12.00; 15.00; 17.00 WIB) for 30 minutes for 6 days

2.6. Data Analysis Techniques

Data analysis began with descriptive quantitative data (HR, IRHR, and CVL). Biomechanical data to generate RULA-REBA scores. Cognitive data for NASA-TLX scores. Anthropometric data to generate percentiles.

1. Physiological Descriptive(Putri, 2019).

$$X = \frac{10 \text{ Denyut}}{n} \times 60 \quad (1)$$

Information :

X = Resting Heart Rate (RHR) and Working Heart Rate (DHR)

n=Counting time

2. Statistical Analysis

Physiological analysis using descriptive statistics (minimum, maximum, mean, and standard deviation), paired-samples t-test to compare resting heart rate (RHR) and working heart rate (DHR) at each observation time, Cohen's d as an effect size (Alrasheeday et al., 2025). Changes in DNK at five observation times (06.00, 09.00, 12.00, 15.00, and 17.00) were analyzed using Repeated Measures ANOVA, because measurements were carried out repeatedly on the same subject, followed by pairwise comparisons using the Bonferroni model to identify pairs of times that were significantly different. (Beyan, Dilek, & Demiral, 2020; Kutluca Canbulat & Demir, 2026; Wolff, Heinemann, Kartes, Ashton-Miller, & Lipps, 2024).

3. %HRR and CVL analysis (Ali, Punnekkat, & Rauf, 2024; Chen & Tserng, 2022).

$$\%HRR = \frac{DNK - D}{DN_{max} - DN} \times 100 \quad (2)$$

Information :

%HRR = %Heart Rate Reversed

DNK = Working Pulse Rate

DNI = Resting Heart Rate

DNmax = Male (220 – age)

$$IRHR = \frac{HR_{work}}{HR_{rest}} \quad (3)$$

$$Cardiovascular Load (CVL) = \frac{HR_{work} - HR_{rest}}{HR_{max} - Age} \quad (4)$$

Information:

HR_{work} = pulse rate during rice field plowing

HR_{max} = Men (220).

HR_{rest} = resting pulse rate (measured after 5 minutes) HR_{work}

$$\%CVL = \frac{100(DNK - DNI)}{DN_{max} - DNI} \quad (5)$$

4. OHT Posture Analysis (Murugan, Ponraja, Varma, & Raj, 2023; Senjaya, Yahya, & Lee, 2022).

$$RULA Score = f(A, B, C) \quad (6)$$

Information:

A = upper arm, lower arm and wrist score;

B = neck, trunk and leg scores;

C = muscle and force (load) adaptation.

$$REBA Score = f(A, B, C) \quad (7)$$

Information:

A = neck, torso and legs;

B = upper, lower arm and wrist;

C = activity, load and coupling score.

5. NASA-TLX Analysis (Fallah, Sefidkar, & Hossein, 2023; Rivera-flor et al., 2019).

$$NASA - TLX = \frac{MD + PD + TD + P + E}{6}; 0 \leq NASA - TLX \leq 100 \quad (8)$$

3. Results and Discussion

3.1. Research Results

3.1.1. Descriptive Study

The workers weighed 52–82 kg (71.30 ± 9.72 kg), were 153–167 cm tall (160.56 ± 4.37 cm), and were 52–65 years old (57.73 ± 3.63 years). The DNK increased progressively from 86.13 at 06.00 to 99.80 at 15.00, then decreased to 75.73 at 17.00. The DNK was always higher than the DNI and the largest difference occurred at 15.00 ($\Delta HR = 46.10$; $p <$

0.001), indicating a peak physiological load (Table 2). There was a very significant difference in DNK between times through Repeated Measures ANOVA, $F(2,742; 79,520) = 369,532$; $p < 0.001$, with all pairwise comparisons significant (Table 3). Increased DNK until 15.00, indicating an accumulation of workload before recovery occurs in the afternoon. Age was significantly associated with CVL ($r = 0.591$; $p < 0.001$), while the strongest relationship was found between IRHR and CVL ($r = 0.876$; $p < 0.001$) (Table 4, 5). Percentile P5 = 153.37 cm, P50 = 160.56 cm, and P95 = 167.75 cm (Table 6). 3:00 PM is a critical point, so that rest arrangements, workload, and anthropometric-based tool design are priorities for OHT intervention.

Table 2. Physiological Characteristics and Responses

Variables	N	Min	Max	Mean $\pm$ SD	F	p-value	Decision	η^2
Body weight (kg)	30	52	82	71.30 $\pm$ 9.721	$F(2,742; 79,520) = 369,532$	< 0.001	Significant	0.927
Height	30	153	167	160.56 $\pm$ 4.37				
Age (years)	30	52	65	57.73 $\pm$ 3.629	Time	Mean DNK	Elementary School	Changes from previous time
DNK 06.00	30	81	92	86.13 $\pm$ 3.803	6	86.13	3,803	
DNK 09.00	30	88	93	91.20 $\pm$ 1.495	9	91.20	1,495	+5.07
DNK 12.00	30	93	99	95.77 $\pm$ 2.079	12	95.77	2,079	+4.57
DNK 15.00	30	98	101	99.80 $\pm$ 1.031	15	99.80	1,031	+4.03
DNK 17.00	30	70	82	75.73 $\pm$ 3.823	17	75.73	3,823	-24.07

Source: processed by IBM SPSS 31 researchers, 2026

Table 3. Comparison of DNI and DNK Based on Observation Time

Time	DNI Mean	DNK Mean	Δ HR	DNI Mean $\pm$ SD	DNK Mean $\pm$ SD	Cohen's d	t	p-value
06.00	54.1	86.13	32.03	54.10 $\pm$ 4.15	86.13 $\pm$ 3.80	-5,666	-31,033	<0.001
09.00	67.03	91.2	24.17	67.03 $\pm$ 2.48	91.20 $\pm$ 1.49	-8,068	-44,193	<0.001
12.00	66.93	95.77	28.83	66.93 $\pm$ 2.57	95.77 $\pm$ 2.08	-9,517	-52,129	<0.001
15.00	53.7	99.8	46.1	53.70 $\pm$ 4.31	99.80 $\pm$ 1.03	-10,522	-57.63	<0.001
17.00	54.03	75.73	21.7	54.03 $\pm$ 4.02	75.73 $\pm$ 3.82	-4,041	-22,133	<0.001

Source: processed by IBM SPSS 31 researchers, 2026

Table 4. Intertemporal DNK Changes Based on Repeated Measures ANOVA and Pairwise Comparisons

Time comparison	Difference	p-value	Repeated Measures ANOVA	Mark	p-value
				$F(2,742; 79,520) = 369,532$	<0.001
06.00 – 09.00	-5,067	<0.001	06.00 vs 09.00	$\Delta = -5.067$	<0.001
06.00 – 12.00	-9,633	<0.001	06.00 vs 12.00	$\Delta = -9.633$	<0.001
06.00 – 15.00	-13,667	<0.001	06.00 vs 15.00	$\Delta = -13.667$	<0.001
06.00 – 17.00	10,400	<0.001	06.00 vs 17.00	$\Delta = +10,400$	<0.001
09.00 – 12.00	-4,567	<0.001	09.00 vs 12.00	$\Delta = -4.567$	<0.001
09.00 – 15.00	-8,600	<0.001	09.00 vs 15.00	$\Delta = -8,600$	<0.001
09.00 – 17.00	15,467	<0.001	09.00 vs 17.00	$\Delta = +15.467$	<0.001
12.00 – 15.00	-4,033	<0.001	12.00 vs 15.00	$\Delta = -4.033$	<0.001
12.00 – 17.00	20,033	<0.001	12.00 vs 17.00	$\Delta = +20.033$	<0.001
15.00 – 17.00	24,067	<0.001	15.00 vs 17.00	$\Delta = +24.067$	<0.001

Source: processed by IBM SPSS 31 researchers, 2026

Table 5. Correlation of Worker Characteristics with Physiological Load

Variables	IRHR		CVL	
	Pearson	p-value	Pearson	p-value
Age (years)	0.236	0.209	0.591	<0.001
Body weight (kg)	-0.073	0.700	-0.151	0.424
IRHR			0.876	<0.001

Source: processed by IBM SPSS 31 researchers, 2026

Table 6. OHT percentiles are normally distributed

Percentile (0)	Z-score	Formula	Height (cm)
P5	-1,645	$160.56 - (1.645 \times 4.37)$	153.37
P50	0	$160.56 + (0 \times 4.37)$	160.56
P95	1,645	$160.56 + (1.645 \times 4.37)$	167.75

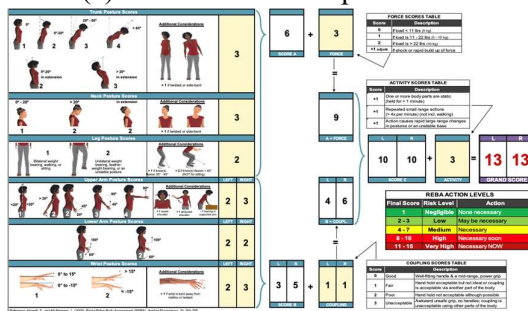
Source: processed by researchers, 2026

3.1.2. Ergonomic Assessment

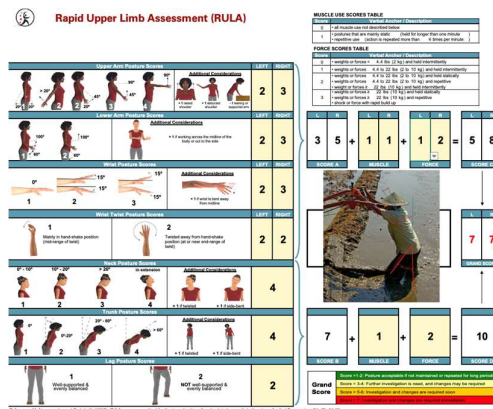
The OHT working posture is in a position of reaching the HT in front of and above the head area. The combination of trunk flexion, neck flexion, arm reach, and unstable footing causes an accumulation of biomechanical loads on the lower back, neck, shoulders, and upper extremities. Assessment of the upper arm angle of 152.57° , accompanied by shoulder elevation and arm abduction, a forearm angle of 122.9° , wrist deviation of 42° , and wrist rotation near the limit indicates a high load on the upper extremities, reinforced by 15° neck flexion, neck rotation, 24.03° trunk flexion, and a rotated or tilted torso position. Static, repetitive muscle use, and shock forces increase musculoskeletal risks. Neck flexion of 15° , trunk flexion of 23° with rotation, unilateral or unstable foot support, knee flexion, load > 3 kg during the HT maneuver (Fig. 3a,b,c,d,f).



(a) OHT Postural Respondent 1

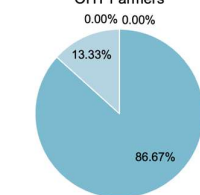


(c) REBA OHT Respondent 1



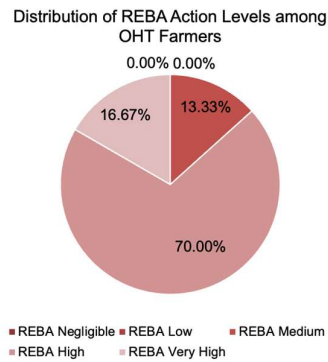
(b) RULA OHT Respondents 1

Distribution of RULA Action Levels among OHT Farmers

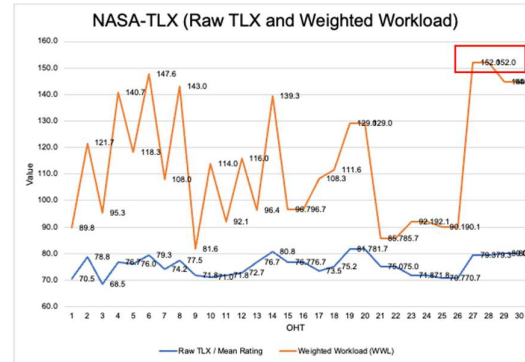


- RULA Acceptable
- RULA Further investigation; change may be needed
- RULA Investigate; change soon
- RULA Investigate; change immediately

(d) RULA OHT



(e) Distribution of REBA Action Levels among OHT Farmers

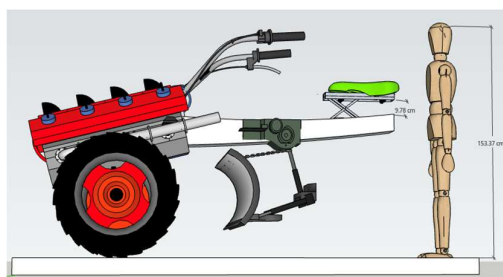


(f) NASA-TLX (Raw TLX and Weighted Workload)

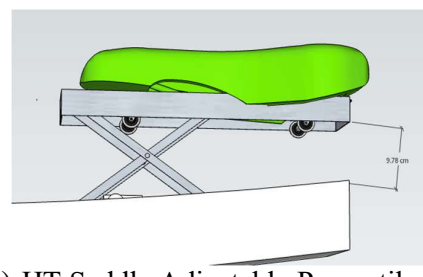
Figure 3. Ergonomic Assessment of OHT Farmer Posture Using RULA, REBA, and NASA-TLX

3.1.3. Percentile-based Recommendation Model

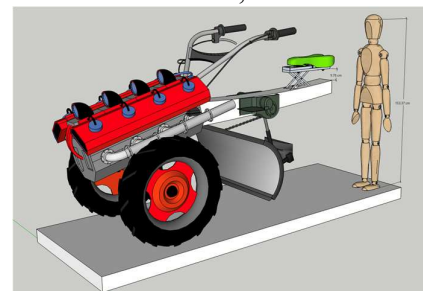
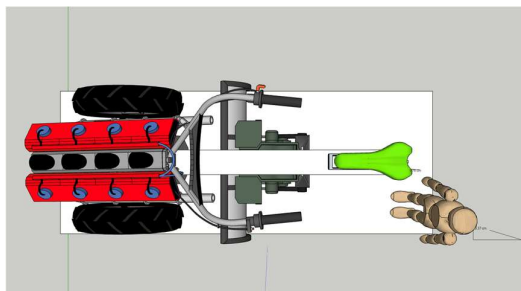
The Hand Tractor (HT) visualization recommendation model integrates the anthropometric dimensions of the OHT with the geometric configuration of the machine, using the 50th percentile as a representation of the median body size. Characteristics of 30 OHTs with a body weight of 52–82 kg with a mean of 71.30 ± 9.72 kg, a height of 153–167 cm with a mean of 160.56 ± 4.37 cm, and an age of 52–65 years with a mean of 57.73 ± 3.63 years. There are anthropometric variations that need to be accommodated in the design. Height is an important parameter in determining the vertical relationship between the operator's body, saddle, and control bar. The normal distribution value, the 5th percentile height is 153.37 cm, the 50th percentile is 160.56 cm, and the 95th percentile is 167.75 cm. The use of P50 in the initial model serves as a reference configuration, the final design with recommendations considers the P5, P50, P95 range as a wider variety of OHT users (Fig. 4a,b,c,d,e).



(a) 50th Percentile HT Model Visual

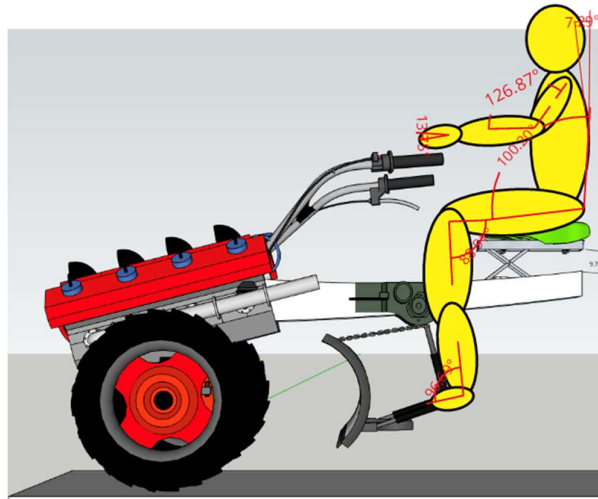


(b) HT Saddle Adjustable Percentile 5th, 50th, 95th



(c) Visual HT Stang top view

(d) Visual HT Perspective



(e) Recommended handlebar-saddle angle sitting posture based on RULA-REBA

Figure 4. RULA-REBA based HT Visualization Model

Source: Sketchup Software and CorelDRAW data processing (2026)

3.1.4. Discussion

A total of 30 OHT operators, all male, with a body weight of 52–82 kg (71.30 ± 9.72 kg) and age 52–65 years (57.73 ± 3.63 years). Left and right RULA scores were identical at 5.47 ± 0.73 (range 5–7), while the left REBA score was 8.70 ± 1.64 and the right 8.77 ± 1.72 (range 7–13). The operators' working postures were at the RULA risk level of investigation and immediate changes are planned, while REBA was predominantly in the high risk category. Small differences between the left and right sides, especially REBA, indicate bilateral postural load variations in OHT activities (Fig. 3b,c). OHT with bilateral assessment of the left and right sides resulted in 60 postural assessment units. RULA showed 52 assessments (86.67%) scored 5–6, while 8 assessments (13.33%) scored 7, indicating the need for immediate to immediate changes in the condition of the right and left sides of the OHT, respectively. This study is in line with evidence that 340 rice farmers in Bangladesh found that 44% experienced MSDs in the past month, with the most common complaints being in the waist/thigh (26%), knees (17%), and neck (17%). Multivariate analysis showed that age >61 years, working >8 hours/day, smoking, sleeping <6 hours, and comorbidities increased the odds of MSDs, while higher education was protective. (Kunwedomo, Angela, Akorsu, Boampong, & Bukari, 2024; Nabi, Rupa, Hossian, Naz, & Hossain, 2025) This is further supported by a study of 157 rice farmers in Roi-Et, Thailand, which showed that 87.3% of respondents were at moderate to high risk of REBA, consisting of 46.5% at moderate risk and 40.8% at high risk. In fact, repetitive movements had an aOR of 1.90, awkward postures an aOR of 1.95, and force exertion an aOR of 2.78 for MSDs. (Jaikla, Tadee, & Baubhom, 2026).

REBA showed 8 (13.33%) assessments at moderate risk, 42 (70.00%) at high risk, and 10 (16.67%) at very high risk. This distribution indicates that the risk is not solely individual. Bilateral postural exposure during HT operation (Fig. 3d, 3e). Raw TLX was highest in OHT19 and OHT20 (81.7), lowest in OHT3 (68.5). WWL was highest in OHT27 and OHT28 (152.0), lowest in OHT9 (81.6) (Table 3f). The OHT operates on soils that are moist to very damp, resulting in soft, slippery, uneven, and low-bearing surfaces. This results

in less stable footing for the operator and increases the force required to control the direction and depth of plowing.(Nabi et al., 2025; Weichelt, Ray, & Keifer, 2019). Tillage to a depth of approximately 15–25 cm produces soil resistance against the plow, requiring the OHT to continuously apply thrust and handlebar control. The interaction between soil resistance, mud, engine vibration, and changes in tractor direction forces the operator to maintain a hunched posture, with the neck lowered, shoulders raised, and wrists bent.(Nwe et al., 2012; Wilhelmsson et al., 2021). OHT must maintain high concentration and alertness because changes in soil conditions, obstacles, plowing direction, and machine stability occur dynamically. These simultaneous conditions increase physical, postural, cognitive, and environmental demands, thus explaining the high ergonomic risks and mental workload during plowing. Human energy requirements are an important aspect in the evaluation of agricultural technology, because improvements in mechanization or technological configuration must not only be assessed in terms of productivity but also from the consequences of the physical demands of OHT.(Daum & Birner, 2022; Msibi, Jakobsson, Skinner, & Naidoo, 2025).

The 9.78 cm saddle adjustment mechanism for the sitting position is adjusted to the difference in height and length of the OHT body segments. This functions so that the use of multi-dimensional saddles can reduce the potential for short OHTs to experience excessive reach, tall OHTs can experience limited space or inappropriate joint flexion. The theoretical height range is 153.37–167.75 cm, the adjustable mechanism as an anthropometric accommodation strategy. Adoption of the saddle as a functional connection between the pelvis, trunk, legs, and control bar so that there is no need for postural compensation when operating the HT (Fig. 4b). Spatial relationship of the OHT, saddle, control bar, wheels, and plow unit. The OHT is positioned on the longitudinal axis of the machine so that the body's interaction with the control system is relatively symmetrical. This configuration has the potential to reduce the need for lateral rotation of the torso and maintain force distribution on both sides of the body. This is the result of the RULA–REBA evaluation, which was conducted bilaterally on the left and right sides. The top view design is aimed at maintaining both upper extremities within the functional reach area, so that the operator does not need to overreach.(Zein, Halim, Azis, Saptari, & Kamat, 2015). HT operation in rice fields, this configuration helps the operator maintain directional control when the machine experiences deviation due to soil resistance, changes in plowing paths, and instability of the land surface as a strategy of the HT mechanical component - anthropometry of the human–machine interaction system (Fig. 4c,d). The pelvic support point, while the handlebars serve as the primary interface for directional control and machine stability. Working conditions in relatively wet, soft, slippery, and uneven rice fields place greater demands on the operator's body stability.

Ergonomic interventions linking anthropometry, biomechanics, work posture, machine control demands, and operator physiological responses (Figure 4e). DNK increased from 86.13 ± 3.80 at 06.00 to 91.20 ± 1.49 at 09.00, 95.77 ± 2.08 at 12.00, and reached 99.80 ± 1.03 at 15.00, then decreased to 75.73 ± 3.82 at 17.00. Repeated Measures ANOVA showed a significant change in DNK over time, $F(2,742; 79,520) = 369.532$; $p < 0.001$. All pairwise comparisons were significant ($p < 0.001$), with the largest increase from 6:00 to 15:00 of 13.67, a decrease of 24.07 from 15:00 to 17:00. Occupational exposure during the plowing period was associated with strong changes in physiological responses throughout

the day. CVL was strongly positively correlated with age ($r = 0.591$; $p < 0.001$), while the associations of body weight with IRHR ($r = -0.073$; $p = 0.700$) and CVL ($r = -0.151$; $p = 0.424$) were not significant.

The OHT ergonomics policy is directed towards Ergonomic-Driven Design (EDD) based on PHEE–SAAML through five strategies: making ergonomics the standard for HT design, accommodating variations in P5–P95 anthropometry, implementing a work–rest schedule based on physiological load, managing individual OHT risks, and conducting continuous validation and standardization to improve operator safety, comfort, and performance sustainability (Table 7).

Table 7. Evidence-Based Ergonomic Policy And Design Framework For Agricultural Mechanization

Insight	Evidence	Policy	Policy Instruments	Outcome
OHT ergonomics as a design standard is designed to be adaptive to anthropometric variations.	RULA 5–7, mean 5.47; REBA 7–13, mean ± 8.77 ; 86.7% OHT high–very high REBA risk	Transforming risk assessment into Ergonomic-Driven Design (EDD)	HT ergonomic design standards; ergonomic design checklist; ergonomic certification before use	Reduction of RULA/REBA and MSDs
	Height: 160.56 ± 4.37 cm; P5 = 153.37 cm, P50 = 160.56 cm, P95 = 167.75 cm	Promoting SAAML (Adjustable Anthropometric Multi-Level Handlebars) and saddle as design principles	Adjustable height/distance specifications; P5–P50–P95; anthropometric design guideline	Improved posture and reach fit
Safety policies based on physiological load, working time and workload capacity and repair cycles	DNK increased at 06.00 to 99.80 ± 1.03 beats/minute at 15.00; ANOVA $F = 369.532$; $p < 0.001$	Developing a Work–Rest Schedule (WRS) as a physiological response	Determining work duration, micro-breaks, activity rotation, and monitoring during critical periods	Controlling the accumulation of fatigue
	Age–CVL: $r = 0.591$; $p < 0.001$; IRHR–CVL: $r = 0.876$; $p < 0.001$; body weight did not show a significant relationship with CVL	Developing risk-based worker management (RBWM)	Periodic physiological screening; operator risk classification; individual WRS recommendations	Placement and workload are more in line with capacity
	PHEE integrates physiological, biomechanical, cognitive, anthropometric, and work time; SAAML becomes the design output	PHEE–EDD–SAAML Policy Framework	Prototyping → comparative testing → evaluation → redesign → standardization	Adaptive and safe HT system.

Source: data processing, 2026

4. Conclusion

4.1. Main Contributions of the Study

The study contributes to the PHEE framework – psychophysiological, biomechanical, cognitive, anthropometric and working time on OHT with the 5th, 50th and 95th percentile EDD–SAAML approach as a strategy to generate human-machine-environment (HME) to produce HT configurations that are adaptive to OHT variations and changes throughout the operating time.

4.2. Key Findings

The study resulted in bilateral left-right OHT posture, left-right RULA scores of 5.47 ± 0.73 with a range of 5–7, respectively; 52 assessments (86.67%) were at a score of 5–6 and 8 assessments (13.33%) obtained a score of 7. REBA assessments with a score of 8.70 ± 1.64 on the left side and 8.77 ± 1.72 on the right side, with 42 assessments (70.00%) in the high risk category and 10 assessments (16.67%) in the very high risk category. The physiological response of the temporal pattern was strong, DNK increased from 86.13 ± 3.80 beats/min at 06.00 to 99.80 ± 1.03 beats/min at 15.00, decreasing to 75.73 ± 3.82 beats/min at 17.00. The change in DNK over time was significant based on Repeated Measures ANOVA, $F(2,742; 79,520) = 369.532$; $p < 0.001$, and all pairwise comparisons showed significant differences ($p < 0.001$). CVL was strongly positively correlated with

age ($r = 0.591$; $p < 0.001$). IRHR was very strongly correlated with CVL ($r = 0.876$; $p < 0.001$).

4.3. Practical Implications

The height variation of the OHT is 153–167 cm, P5 (153.37 cm), P50 (160.56 cm), and P95 (167.75 cm) percentiles. The need for SA configuration to accommodate the anthropometric variations of the OHT. The application of SAAML as an anthropometric accommodation strategy to adjust the saddle height and handlebar distance to the JT, the position of the shoulder, arm, wrist, neck, and trunk. The design configuration considers the grip angle and operator position to reduce overreaching, body rotation, shoulder elevation, and postural compensation during HT maneuvers. At the work system level, the increase in DNK until 15.00 indicates that this period is a critical point of physiological load so that it can be used as a basis for determining the Work-Rest Schedule (WRS).

4.4. Research Limitations

Observation of land processing activities with certain environmental conditions and HT characteristics, so that variations due to soil type, humidity, land slope, operating speed, vibration, temperature, and machine characteristics cannot all be carried out experimentally.

4.5. Recommendations and Future Research Agenda

The framework needs to be directed at experimental validation of the SAAML design through the development and testing of HT prototypes, comparing HT with existing handlebars and SA based on HR, IRHR, CVL, DNK, RULA, REBA, NASA-TLX indicators, biomechanical parameters to determine the magnitude of workload changes after the intervention. Longitudinal research to evaluate the relationship of ergonomic exposure with Musculoskeletal Disorders (MSDs).

Appendix

An appendix not.

Author's Contribution and CRediT

Julianus Hutabarat (corresponding author-first author) contributed to Writing-Original Draft, Conceptualization, Formal Analysis, Software, Data Curation and Methodology.

Lalu Mulyadi contributed to Resources, Conceptualization, Formal Analysis, Validation, Supervision and Methodology.

Dimas Indra Laksmana contributed to Data Curation, Validation, Methodology, Formal Analysis, Writing-Review and Editing.

Sanny Andjar Sari contributed to Review & Editing, Validation, Project Administration, and Validation.

Johan Alfian Pradana, Renny Septiari contributed to Project Administration, Software, Data Curation and Methodology.

Renny Septiari, Johan Alfian Pradana contributed to Data Curation, Software, Formal Analysis, Validation

All Authors Have Read and Approved the Final Work.

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