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The Effects of Muddy Terrain on Lower Extremity Loading During the Paddy Planting Activity

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Abstract

In this research, 30 rice farmers were examined to investigate the effect of muddy terrain on lower extremity loadings during planting chores associated with rice production. A comparison was made against the force loadings on each lower extremity joint when rice cultivating on a flat, firm surface (rigid ground; "no-force") and muddy terrain (mud-force) using 3D Static Strength Prediction Program (3DSSPP). This research choses the toe-off stage of gait for the study since this is when a person raises their right foot off the work surface while planting. Each farmer's tensile viscosity force of mud was calculated individually. The study's findings indicate that muddy working surfaces place an increased load on lower extremity joints. The strain on all joints was found to be much greater in the mud-force condition than in the no-force condition ($p<0.05$). According to the descriptive data for the lower extremity joints, the tensile force of the right and left ankles rose by a ratio of 1.03 to 2.46 times. This study may result in reworking the work-rest schedule and designing an assistive device to decrease lower extremity harm caused by working in a muddy work environment.

Keywords— Biomechanical loads, Work environmental hazard, Musculoskeletal disorders, Muddy work environment, Lower extremity injury, Rice planting process

Introduction

Rice is the predominant carbohydrate source in the majority of Asian countries. Rice consumption is lower in countries outside of Asia, including the United States, Australia, and Europe, according to the International Rice Research Institute (IRRI). Indonesia will be the fourth largest milled rice producer in the world by 2021, according to Mundi Index [1]. The Indonesian Central Bureau of Statistics (BPS) reported that rice production increased by 0.08 percent from 2019 to 2020 [2]. Rice production and consumption are both predicted to increase in the future. As a result of this growth, the necessity for a safe and healthy working environment for rice farmers becomes critical in order to ensure labor availability.

Musculoskeletal disorders (MSDs) are prevalent among rice farmers and might manifest in any part of the body within a year [3]. Rice farmers are the four most frequent outpatients. Over 95% of rice farmers suffer from MSDs or accidents, and 95% have chronic pain. Lower extremity MSDs are prevalent among rice farmers. Previously, the prevalence of lower extremity musculoskeletal disorders (MSDs) was believed to reach between 10% and 41% [5]. Other rice growers experienced hip discomfort at a rate of 41%, knee pain at a rate of 35.44 percent, and ankle and foot pain at a rate of 10.3 percent [3]. Rice farmers had a higher prevalence of lower extremity MSDs than those in other manual jobs [6].

MSDs can be discovered at every stage of the rice cultivation process, from plowing to seeding, planting, and nursing. Rice planting has been shown to produce lower extremity pain and ergonomic problems [7]. The knee bends and the right arm is extended away from the body in an extreme forward bent and twisted position to plant rice sprouts below the knee. This pose is completed by holding a bundle of rice sprouts in the left hand. Lower extremity loading is increased as a result of an unpleasant position and excessive exertion [8-9]. As a result of exposure, this force produces tissue damage and inflammation. Prolonged exposure might result in pain, which can result in an decrease in productivity. Additionally, rice planting is typically carried out barefoot on muddy terrain. The viscosity of the mud increases the force loading on the lower extremity joints during the stepping phase due to the mud's density [12].

Mud requires a finite yield stress (i.e., the plot of shear stress versus shear strain does not intersect the origin) and is a non-Newtonian fluid in order to flow. When subjected to mild stress, it behaves like a solid, but when subjected to high stress, it behaves like a viscoplastic substance (Bingham plastic). When a farmer walks through mud, the farmer's lower extremity muscles must work harder due to the higher viscosity generated by their combined weight. The purpose of this study is to determine the effect of muddy ground on lower extremity loads associated with rice planting activity. The researchers compared the forces experienced by employees on a flat, solid surface to those encountered on a real work surface using force measurements at each lower extremity joint (muddy terrain).

Material and methods

Participants

Thirty experienced rice farmers (male and female, aged 38 to 70) were chosen from a community of rice farmers in the Sewon subdistrict, Bantul District, Yogyakarta Province, Indonesia. Participation in this event needed at least one year of rice farming expertise. To be eligible for the trial, individuals had to be free of lower extremity injuries or prior histories that would have impacted their alignment. Participants were not permitted to participate in the study if they had a prior medical history that could affect their lower extremity alignment.

Description of the activity

The figures 1 and 2 illustrate the instructions provided to participants to complete the simulated rice planting activity under two distinct conditions: without force and with mud-force (conducting task on muddy terrain). In this investigation, rice planting was conducted in an actual rice field. In both testing scenarios, farmers were asked to hold a rice sprout with an average weight force of 1.5 kg in the left hand and 0.15 kg in the right hand. A high-angle video camera was used to record every action throughout the planting performance simulation. Three perspectives of motion were filmed during the planting process (front, rear, and side). The sequence of the conditions was chosen at random at the commencement of the experiment. To simulate planting, the farmers were instructed by their instructors to use the right hand to force a tiny package of rice sprouts into the ground. Participants are instructed to take a step backward by raising and laying their right foot ere commencing the next row. Each participant was directed to take six steps backward and counterclockwise, then repeat six steps backward at a step length of 35 to 40 cm and a speed of 60 beats per minute. The metronome was utilized to regulate the speed of upper-body mobility and steps during planting chores. Each condition required a total of four replications. To avoid having to redo anything or making a mistake, participants first practiced the movement rate and stepped length. This study established a 5-minute interval between conditions on the advice of [13]. Five minutes of rest or relaxation time was proven to be useful in alleviating muscle fatigue in a study.

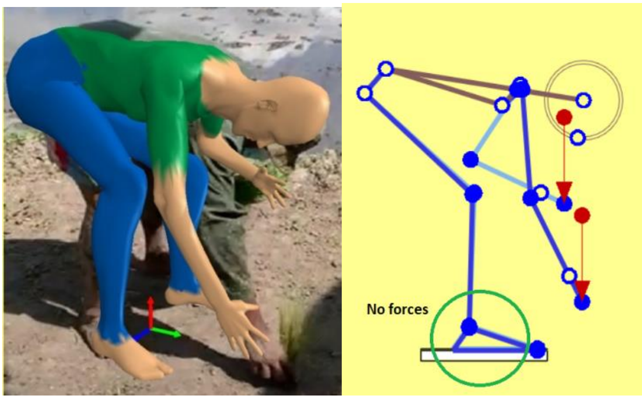

Figure 1. Simulated planting task performance without force condition (hard surface; without extra external force on feet)

The depth of the mud layer was based on the average immersion depth of farmer's legs in the mud, namely 20 cm regained from direct measurements in the field.

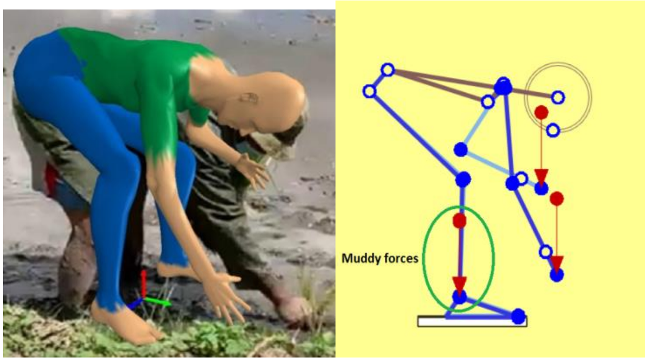

Figure 2. Simulated planting task performance with mud force (muddy terrain; including tensile viscous force on feet)

Mud viscous force calculation

Shear viscous force of mud were estimated with equation (1) as follows [14]:

$$F = \eta A \frac{v}{l} \qquad (1)$$

$$A = 2\pi rh \qquad (2)$$

Newton's shear viscous force, F, is used to determine the shear viscosity of mud. The average viscosity property of mud (η = 3598.07 Ns/m^2) was determined using the Rotational Rheometer Gemini 200Hr nano during laboratory testing of dynamic shear force on samples (taken from the rice field). To estimate one geometry of each farmer's lower legs, it was assumed that the lower extremities were cylindrical objects. Thus, using the equation (2), the area of the lower extremities impacted by viscous force (A, m^2) may be calculated. The velocity of a farmer's foot lifting out of mud is measured in meters per second using the Suunto 9 Black wrist band (Suunto Oy, Finland). While l denotes the width of the fluid in meters perpendicular to the velocity, m denotes the volume of the fluid in cubic meters (equivalent to the radius of lower extremity, r, in this state). r is the radius of the farmer's lower extremities, which is determined from their leg radius measurements. Additionally, h denotes the lower extremity height, which is the average height of the farmer's legs settling into the mud.

Force analysis on lower extremity joints

Compressive and tensile forces were estimated on the right and left hips, knees, and ankles utilizing the 3D Static Strength Prediction Program version 6.0.6. (3DSSPP; Center of Ergonomics, University of Michigan). The static position, which happens when lifting the foot off the planting area, was the subject of this study. Each farmer's demographic information was entered into the 3DSSPP software. For all farmers, a bundle of rice sprouts weighted 15 N on the left hand and 1.5 N on the right hand. The forces exerted on each lower extremity joint are depicted in figures 1 and 2 under the no-force and mud-force circumstances (with and without tensile viscous force acting on the feet, respectively). All external inputs were calculated using only vertical force inputs.

Hypotheses

Based on literature reviews, this study predicted an increase in loading on lower extremity joints when farmers conduct rice planting in muddy terrain, compared with flat rigid terrain. The reviews showed that the lower extremity joints stand a high risk of injury when exposed to muddy terrain conditions.

Statistical analyses

The independent variable used to conduct this study is the working surface conditions for rice cultivation, namely (1) rigid (baseline) and (2) muddy terrains. Meanwhile the dependent variables, which are response measures retrieved from 3DSSPP software, include forces acting on the right and left hip, knee and ankle joints. This research used a paired t-test to contrast biomechanical force on the lower extremity of farmers when they performed the planting task on both surfaces. Furthermore, the Shapiro-Wilk test was used for the normal distribution confirmation test for mud viscous force on each the lower extremity of farmers since the data set in this study was smaller than 2000. The analyses used the SPSS version 26.0 software (IBM Corporation) on a significance level of α=0.05.

Results

Participants

The demographic characteristics and descriptive statistics of the participants are shown in table 1, where eighty percent had a normal body mass index.

Table 1. The demographic characteristics and descriptive statistics for the participant (n = 30)

Characteristics	N (%)	Mean ± SD
Sex		
Male	11(36.67)	
Female	19(63.33)	
Age (years)		56.33 ± 8.87
Height (cm)		158.23 ± 6.97
Weight (kg)		54.58 ±

Characteristics	N (%)	Mean ± SD
BMI (kg/m^2)		10.29 21.55 ± 3.77
Working experience (years)		21.93 ± 13.42

Determination of farmer lower limb geometry and mud shear force

The descriptive statistics for the determination of the right and left sides of farmers lower limb geometry and shear viscous force data are shown in the table 2.

Table 2. Descriptive statistics of determination of farmer lower limb geometry and shear viscous force data

	Male		Female		Total	
	Mean	SD	Mean	SD	Mean	SD
h (m)	0.21	0.02	0.20	0.01	0.20	0.02
v (m/s)	0.17	0.07	0.16	0.08	0.17	0.08
r (m)	0.03	0.01	0.04	0.01	0.03	0.01
A (m^2)	0.04	0.02	0.04	0.01	0.04	0.01
F (N)	416.54	170.44	356.50	170.30	378.52	172.79

The geometric data of lower extremity of the participants include height (h) and radius (r) of lower extremity, which ranges from 0.18 to 0.25 m and 0.01 to 0.05 m, respectively. The area of lower extremity (A) calculated for each participant resulted in values ranging from 0.01 to 0.06 m2. Meanwhile, the individual average speed of foot (v) captured based on video analysis ranged from 0.04 to 0.34 m/s. Based on equation (1), external shear viscous force acting on farmer lower extremity from walking on the mud (F) ranged from 103.62 to 769.28 N.

Biomechanical force analysis

Biomechanical force analysis was conducted to determine the effect of force acting on lower extremity joints of farmers during the planting stage of rice cultivation. This force was calculated on lower extremity using the 3DSSPP software based on factors of gender, height, weight, posture, and external force, such as hand loads and mud viscosity. The results of Paired T-Test of biomechanical force between muddy work surface condition and flat hard condition are shown in figure 3.

In this study, heavy weight led to increased leg immersing height (h) with a rise in the area of mud surface (A) and the viscous force acting on the leg (F). Correlation analyses were conducted to investigate the relationships among individual factors of weight, BMI, leg immersing height and area, foot lifting velocity, and biomechanical force on hip, knee, and ankle joints as shown in tables 3 to 8.

The body weight and BMI indicated a positive correlation between mud force and the right and left sides of participants hips and knees. Subsequently, the height indicated a positive correlation between mud force and left hip and left ankles of participants. Furthermore, the velocity of foot lifting out of mud indicated a positive correlation between mud force to ankle (both right and left side) of participants.

Discussion

Differences in individual characteristics and foot lifting speed were due to the mud force acting on lower extremity parts of the participants. Based on equation (2), farmers with greater height of the legs settling in the mud tend to experience a more significant contact area with increased viscosity force. Therefore, it is positively correlated to weight of the individual [15]. Furthermore, farmers with more weight are likely to immerse deeper into the mud terrain, compared with those with less weight. Farmers with the ability to lift their legs out of the mud terrain with higher speed, then leads to greater dragging force thereby leading to mud viscosity.

Biomechanical force analysis was conducted to determine the effect of force acting on lower extremity joints of farmer during the planting stage of rice cultivation. This force was calculated by 3DSSPP software based on various factors, such as gender, height, weight, posture, and external force. The Paired T-Test results revealed significant force effects on hip, knee, and ankle of lower extremities due to muddy work surface conditions, which are significantly higher than the load from flat hard condition. The ratio of differences on right (2.46 times) and left (2.37 times) ankle joints was much higher than those on hip and knee joints at 1.04 and 1.03, respectively.

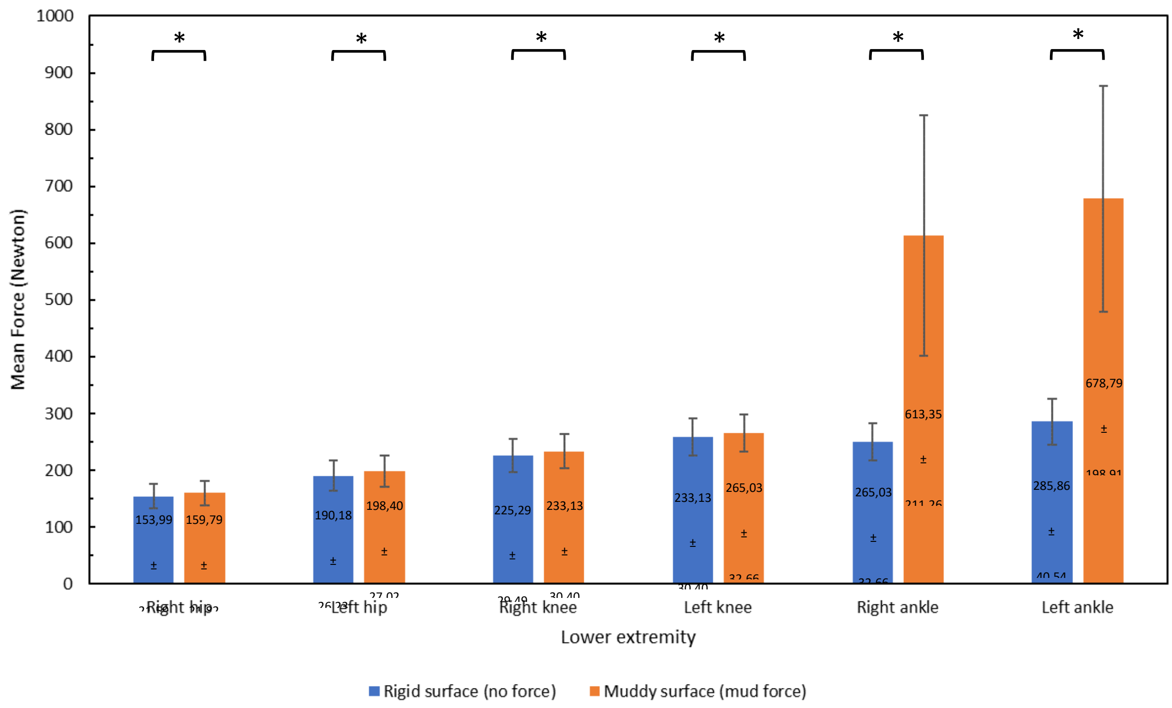

Figure 3. Comparison of biomechanical force on each lower extremity joint between no force and mud force condition

(* indicated significant difference at p<0.05)

Table 3. Correlation analyses between force acting to right hip of subjects and demographic characteristics

	Height	Weight	BMI	h	v	A
Pearson correlation	0.289	0.466**	0.355	-0.284	0.142	-0.310
Sig.(2-tailed)	0.122	0.009	< 0.0001	0.128	0.454	0.096
N	30	30	30	30	30	30

Table 4. Correlation analyses between force acting to left hip of subjects and demographic characteristics

	Height	Weight	BMI	h	v	A
Pearson correlation	0.453*	0.790**	0.639**	0.142	-0.110	0.123
Sig.(2-tailed)	0.012	< 0.0001	< 0.0001	0.453	0.563	0.518
N	30	30	30	30	30	30

Table 5. Correlation analyses between force acting to right knee of subjects and demographic characteristics

	Height	Weight	BMI	h	V	A
Pearson correlation	0.338	0.721**	0.598**	-0.280	0.107	-0.310
Sig.(2-tailed)	0.067	< 0.0001	< 0.0001	0.134	0.575	0.096
N	30	30	30	30	30	30

Table 6. Correlation analyses between force acting to left knee of subjects and demographic characteristics

	Height	Weight	BMI	h	v	A
Pearson correlation	0.328	0.650**	0.551**	0.060	-0.067	0.063
Sig.(2-tailed)	0.077	< 0.0001	0.002	0.752	0.726	0.742
N	30	30	30	30	30	30

Table 7. Correlation analyses between force acting to right ankle of subjects and demographic characteristics

	Height	Weight	BMI	h	v	A
Pearson correlation	0.223	0.175	0.096	-0.042	0.868**	0.195

Sig.(2-tailed)	0.237	0.355	0.615	0.827	< 0.0001	0.303
N	30	30	30	30	30	30

Table 8. Correlation analyses between force acting to left ankle of subjects and demographic characteristics

	Height	Weight	BMI	h	v	A
Pearson correlation	0.518**	0.345	0.145	-0.011	0.784**	0.225
Sig.(2-tailed)	0.003	0.062	0.445	0.956	< 0.0001	0.232
N	30	30	30	30	30	30

* Indicated correlation is significant at the 0.05 level (2-tailed)

** Indicated correlation is significant at the 0.01 level (2-tailed)

Planting tasks were commonly carried out with bare feet on a slippery, muddy walking surface. This represents a challenge for controlling body alignment [16], and therefore, leads to an increased risk of leg injury [17-18]. The abnormal biomechanics of leg joints are due to adverse effects between ground reaction force and abnormal rotational alignment of the lower extremities. Such effects usually occurred on the weight-bearing surface during prolonged walking in the stance phase of gait [16][19-20]. Also, the muddy environment condition also increases the force acting on lower extremity joints due to viscous force [21].

Work related MSDs due to muscle and nervous tissue supported structure injury as well as excessive joint loading. Hip and knee osteoarthritis are identified to be common for lower extremity MSDs in rice farmers [22], and are associated with heavy labor osteoarthritis [23-24]. In line with preliminary studies, this study found that load on hip, knee, and ankle joints from muddy work surface condition was significantly higher than those from flat hard condition. Force exertion in planting tasks, due to mud viscosity in addition to heavy lifting, carrying, and prolonged standing while performing awkward postures, tends to overload muscles, tendons, ligaments and joints [25-26]. The joint, bone and cartilages can be injured due to increased shear, torsion and load on the joint. This was also in line with the physical examination study of [27], which indicated the structural origin of pain in rice farmers to be most prominent at knee (54.61%) and hip (22.18%) joints.

According to preliminary studies, dragging forces due to mud viscosity are also related to individual factors, such as weight and foot lifting velocity, which are correlated to biomechanical loads on lower extremity joints. Previous study on demographic risk factors of rice farming activity [7] found that individual factors of farmers BMI are associated with MSDs [5][18][28-29]. Furthermore, high BMI is related with lower extremity MSDs, particularly knee pain in overweight individual (BMI ≥ 25 kg/m2) [30-31]. Weight increase in individual would lead to upsurge in lower limb joint loadings, thereby resulting in leg injury. In this study, heavy weight led to increased leg immersing height (h), a rise in the associated mud surface area (A) and increase in viscous force acting on leg (F). Correlation analyses were conducted to investigate the relationships among individual factors of weight, BMI, leg immersing height and area, foot lifting velocity, and biomechanical force on hip, knee, and ankle joints, which are shown in tables 3 to 8. The relationships also supplement those in preliminary studies [7] indicating weight as one of the risk factors of lower extremity MSDs, which contribute to compression and tensile forces. These findings can function as an extra guideline for specific high-weight rice farmer populations when performing planting tasks in order to minimize risk of lower extremity injury. Furthermore, the positive relationship results between leg lifting velocity and force on lower extremity joints can be also used as a movement strategy guideline, specifically slower lifting velocity recommendation, to rice farmers in order to expose them to less viscous force while working on the muddy terrain. Previous studies also indicated slower motion requirements lead to lower risk exposure and decreased discomfort [8-9].

Therefore, by analyzing all results, it can be perceived that muddy work terrain posed risk to all lower extremity parts. The findings can act as supplementary support toward the high prevalence of lower extremity in farmers as indicated in preliminary studies [3][5][32-33]. Regarding specific lower extremity, this study found that the highest effects in terms of force, muscle activity and pain are found on farmers knees. According to knee alignment, a distribution of loading is generated from control alignment of hip, knee and ankle [34-35]. This is because planting tasks involve repetitive awkward postures performing in extreme environment, which might result in increasing risk factors for knee injury [18][36-37][38-39]. These exposures are associated with knee pain due to increased excessive load, which leads to fatigue and pain. Also, prolonged walking in slippery ground, repetitive lower limb motion and heavy weight carried out during this process represented a challenge for controlling the lower limbs. Hence, such body control difficulty leads to abnormal alignment and risk of injury, especially to lower legs and feet.

The findings of this study are in line with previous studies focusing on work injury for Thai rice farmers [27], showing that during planting, knee part endangered to the highest hazard in terms of pain perception, ergonomic risk, joint and muscle impairments, as well as structural malalignment. With additional impacts from planting activity on muddy terrain, farmers knees need to be emphasized for developing movement guideline, personal protective equipment or assistive device to prevent lower extremity injury during rice cultivation task performance. Subsequently, this research covered some limitations and assumptions, with the viscous force measured by calculating farmer leg and foot as a single-cylinder object. Further research needs to add more accurate farmer lower limb geometry.

Conclusion

The load on hip, knee, and ankle joints from muddy work surface is significantly higher than the flat hard condition. Furthermore, the biomechanical loads on lower extremity joints were related to individual factors, such as weight and foot lifting velocity. Specifically, farmers with more weight and those with the ability to lift their feet faster, contributed to higher biomechanical force on joints. The results can perform as an extra guideline when performing planting tasks in order to minimize risk of lower extremity injury, especially in hip, knee, and ankle.

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