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Effects of muddy terrain on lower extremity muscle activity and discomfort during the rice planting process

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ABSTRACT

The agricultural industry in Thailand and many Southeast Asian countries relies heavily on manual labor with little utilization of advanced machinery. Prior investigation of the rice cultivation process indicated a high prevalence of musculoskeletal disorders and abnormal alignments in lower extremities (LEs) of Thai farmers. Since most tasks are typically performed with bare feet in heavy, muddy terrain, higher LE muscular force is required to compensate for mud viscosity. Consequently, this study investigated effects of muddy terrain on LEs of 30 experienced famers during simulated planting tasks of the rice cultivation process. Muscle activity and discomfort perception of LE joints were compared between rigid ("No-Force") and muddy ("Mud-Force") surface conditions, revealing significantly increased muscle activity and discomfort perception of knee and ankle in muddy work environments. The resulting high risk of knee and ankle injury for rice farmers should therefore be attenuated by development of appropriate protective equipment or assistive devices.

Relevance to industry: The working surface constitutes a physical workplace environments with potential direct impact on productivity and safety of the workforce. In the agricultural industry, workers typically perform tasks on muddy terrain where, besides common slips, trips and falls, mud viscosity might intensify the force and lead to potential injury to the lower limbs.

1. Introduction

The agricultural sector represents the major industrial branch of Thailand and of most Southeast Asian countries. While some production processes incorporate advanced agricultural machinery, most tasks primarily require manual work efforts involving strenuous activities. In Thailand, the rice production industry is of significant importance and generates the second-largest market volume of exported agricultural products (Ministry of Commerce of Thailand, 2017). However, the rice-farming activity is, by nature, ergonomically hazardous due to commonly requiring repetitive performance of awkward postures and forceful exertions (Reid et al., 2010; Fathallah, 2010). The rice cultivation process includes multiple stages (Mokkamul, 2006), of which most require farmers to perform cultivation activities in muddy work terrain. Such a heavy and viscous muddy work environment causes farmers to preferably perform tasks without footwear. Unsurprisingly, a high prevalence of musculoskeletal disorder (MSD) in lower extremities (LEs) was therefore observed among rice farmers in Thailand (10.29–41.16%) (Puntumetakul et al., 2011). Karukunchit et al. (2015) reported Thai rice farmers to exhibit a high percentage of abnormality of LE alignment (11.24–36.14%) and identified specific demographic factors, i.e. gender, body mass index, age and years of farming experience, to be associated with LE malalignment. Several previous studies evaluated the ergonomic risk of agricultural work (e.g., Meyers et al., 1997; Fathallah et al., 2008; Fathallah, 2010; Kirkhorn et al., 2010), including a study conducted in our group focusing on the specific analysis of the rice cultivation process (Karukunchit et al., 2014b). A literature review revealed the cultivation task performance to pose a high risk in terms of repetitive movement, awkward postures and excessive force. Such occupational factors create high loading on the trunk and lower limbs (Reid et al., 2010), leading to tissue injury and inflammatory responses. Moreover, long-term exposures may result in pain and therefore limit work productivity (Barbe and Barr, 2006; Marras et al., 2009). Beyond this, as mentioned previously, rice cultivation activities are typically performed with bare feet on muddy terrain, thus intensifying the extent of force on the lower limbs (Tropea et al., 2007).

Mud is a suspension of water and soil often categorized as non-

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Newtonian fluid. The viscosity characteristics of mud are mainly determined by the ratio of water and solid particles in the suspension and vary with external force and time of exposure (Schramm, 2006). When farmers perform work activity on muddy terrain, the force resulting from body and tool weight induces high mud viscosity and, therefore, increases both the force acting on joints and the muscular force requirements in the LEs of farmers (Tropea et al., 2007). Despite the obvious impact on the health and performance of the agricultural workforce, studies of the relationship between muddy ground conditions and risk of injury has mostly been restricted to the area of sport sciences. For example, Ramirez et al. (2006) collected evidence for an increased injury rate of American footballers when playing on wet or muddy surfaces, as compared with on normal (dry) surfaces. More specifically, Bartlett (2002) indicated that mud-based grounds increase the likelihood of inversion injuries of the ankle joints. However, these studies were mostly focused on slip injury, with less consideration about potential injury from excessive muscular force. Recent investigations of locomotion performance (e.g., speed, force and efficiency) for robots walking on soft, muddy substrates (Ren et al., 2013; Zhang et al., 2016) revealed that, when the ground characteristics resembled that of a thick fluid, the robot's resultant speed, propulsive force, and propulsion efficiency decreased markedly. Another interesting implication of this study was the influence of an adjustable leg geometry on the propulsion efficiency in media of varying viscosity, which could be successfully adapted to enhance overall locomotion performance in different environments. In analogy, human gait behavior is adapted during walking on muddy terrain to compensate for the loss of walking/propulsion efficiency experienced in fluid-like material. Consequently, different activity levels and/or sets of muscles are utilized compared to normal gait on solid ground. Unfortunately, only a limited number of studies investigating the effects of muddy ground conditions on human performance in industrial areas have been conducted to date.

A preliminary study conducted recently in our group investigated the effects of viscous force of muddy terrain on LE joints during the performance of planting tasks in the rice cultivation process (Juntaracena and Swangnetr, 2016). The planting process was selected as the required tasks therein were previously found to pose the most severe ergonomics risk and to induce the highest perceived pain thresholds on farmers (Karukunchit et al., 2014b). Juntaracena and Swangnetr (2016) compared the force loadings on each LE joint of human models between working on a flat hard surface (rigid ground) and real work surface conditions (muddy terrain) by using the 3D Static Strength Prediction Program (3DSSPP; Center of Ergonomics, University of Michigan). A specific posture in which the foot is lifted off the work surface while performing planting activities was selected for the study due to being strongly associated with tensile viscous force. The results illustrated an increase of force on LE joints in response to the muddy working environment. In participants assuming the selected posture, the knee was found to be exposed to the greatest force increase due to mud viscous force. However, a number of inherent limitations of this study have to be considered. The viscous force was calculated using averaged mud viscosity and by simplifying the complex shape of the farmer's leg and foot to a single cylindrical object. Moreover, locomotion in muddy terrain involves complex locomotor-ground interaction, which is difficult to integrate into an applicable model. Due to the complexity of the force equation for a muddy substrate, a comprehensive physical model able to predict the locomotive efficiency in muddy environments has yet remained elusive (Zhang et al., 2016). Nonetheless, prior studies have investigated and developed models for estimating the locomotion performance on granular substrates, albeit such media are relatively simple compared to mud (e.g., Li et al., 2013). To overcome this limitation, Zhang et al. (2016) suggested and conducted experimental assessment of locomotion performance in muddy terrain.

Previous studies investigating ergonomic risks of force, posture and motion in agricultural work (e.g., Reid et al., 2010; Fathallah, 2010) put only limited emphasis on the influence of the working surface, which can have a direct impact on efficiency and safety of the workforce. Therefore, this study attempted to examine potential hazards from agricultural process environments due to the muddy work terrain associated with rice cultivation. Besides common investigations of slips, trips and falls, mud viscosity associated with tensile force might intensify LE muscular force of rice farmers (Tropea et al., 2007) and lead to potential LE injury (Davis and Kotowski, 2007; Naidoo et al., 2009; Reid et al., 2010). As adaption of human gait behavior by utilizing different activity levels and/or sets of muscles may be induced to compensate for the loss of propulsion efficiency during walking on muddy terrain, physiological responses to muscle activation levels were investigated in order to empirically identify the most affected muscles from working on muddy terrain. Electromyography (EMG) has been established as a sensitive tool for monitoring effects of external force on the body in terms of work posture control, levels of muscular use and endurance (Konrad, 2005). Perceived discomfort ratings were also included in the assessment to subjectively confirm the effects of muddy terrain by comparison with discomfort ratings for working on rigid ground. The LE-part most severely affected by working on a muddy surface is anticipated to be exposed to the highest risk of injury, and therefore should be considered as the priority for developing personal protective equipment or assistive devices in order to prevent LE injury in rice farmers.

2. Methods

2.1. Participants

Thirty experienced Thai rice farmers participated in this study, including 15 males and 15 females, within an age range of 20–40 years. Other demographic characteristics of the participants included height ranging from 146 to 178 cm and weight ranging from 45.3 to 78 kg, which translated to BMIs of 16.05–26.96 kg/m^2. Participants were required to have at least one year of experience in rice cultivation. None of the participants had current injury to the LEs. Participants were excluded from the study if they reported back, leg and foot pain within two weeks prior to testing, such as gouty arthritis, rheumatoid arthritis, or ankylosing spondylitis.

2.2. Experimental mud sample preparation

To emulate the characteristics of mud found at the actual planting site, laboratory testing of the viscosity parameters based on dynamic shear force using a Rotational Rheometer (Gemini 200Hr nano) was conducted on “fresh” mud and a set of “experimental” mud samples collected from a typical rice planting site (Meung district, Khon Kaen province). The experimental mud samples were prepared in an 85 cm × 120 cm tray with a mud layer height of 18 cm (see Fig. 1), and naturally dried in a temperature-controlled room for 3 days. The height of the layer was based on the average immersion depth of farmer's legs

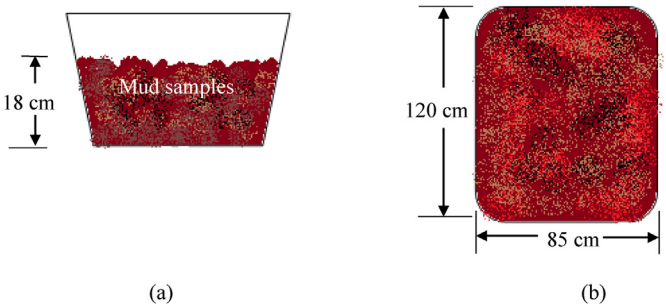

Fig. 1. Mud samples contained in a tray shown in: (a) side view and; (b) top view.