

รายงานวิจัยฉบับสมบูรณ์

โครงการการออกแบบเทคโนโลยีอำนวยความสะดวกสำหรับการป้องกัน
ความผิดปกติของระบบกระดูกและกล้ามเนื้อที่เกิดจากการประกอบอาชีพ
โดยพื้นฐานจากกายอุปกรณ์ของผู้พิการ

Assistive Technology Design for Occupation-induced
Musculoskeletal Disorder Prevention based on Congenital
Disability Orthotic Devices

โดย ดร.มานิดา สว่างเนตร นอยแบร์ท

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มหาวิทยาลัยขอนแก่น

สนับสนุนโดยสำนักงานกองทุนสนับสนุนการวิจัยและมหาวิทยาลัยขอนแก่น

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Project Title : Assistive Technology Design for Occupation-induced Musculoskeletal Disorder Prevention based on Congenital Disability Orthotic Devices

(ชื่อโครงการ) การออกแบบเทคโนโลยีอำนวยความสะดวกสำหรับการป้องกันความผิดปกติของระบบกระดูกและกล้ามเนื้อที่เกิดจากการประกอบอาชีพโดยพื้นฐานจากกายอุปกรณ์ของผู้พิการ

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(ระยะเวลาโครงการ)

งานวิจัยที่ผ่านมาแสดงให้เห็นว่าความพิการแต่กำเนิดอาจมีผลทางกายภาพและการรับรู้คล้ายกับความพิการอันมีผลเนื่องมาจากสถานการณ์ที่พบในผู้ประกอบอาชีพ เทคโนโลยีอำนวยความสะดวกหลายประเภทที่ออกแบบมาสำหรับคนพิการ ได้นำไปใช้กับผู้ใช้งานทั่วไปที่มีการดำเนินงานในสภาพแวดล้อมที่รุนแรง งานวิจัยก่อนหน้านี้ของคณะผู้วิจัย (ได้รับการสนับสนุนจาก สกว.) ได้ดำเนินการศึกษาเปรียบเทียบสภาพทางกายภาพของเกษตรกร (ชาวนา) และผู้พิการแต่กำเนิดหรือความพิการที่เกิดจากโรค (กลุ่มผู้ป่วยสมองพิการ (cerebral palsy, CP)) ผลการศึกษาแสดงให้เห็นว่าประชากรทั้งสองกลุ่มสามารถเชื่อมโยงกันได้ในแง่ของความชุกของอาการผิดปกติของอาการผิดปกติของการหมุนของเท้าเข้าข้างใน (foot pronation) และข้อเท้าแบบโค้งเข้า (knee valgus) ระดับการรับรู้การปวดเท้า และสาเหตุความเจ็บปวดเนื่องมาจากระบบกระดูกและกล้ามเนื้อเท้าและเข่าที่บกพร่อง จากการศึกษาที่ผ่านมาแสดงให้เห็นว่าการออกแบบเทคโนโลยีอำนวยความสะดวกสำหรับสองกลุ่มประชากรนี้มีความเป็นไปได้ การศึกษานี้มีวัตถุประสงค์เพื่อพัฒนาออกแบบและทดสอบต้นแบบของเทคโนโลยีอำนวยความสะดวกสำหรับการป้องกันความผิดปกติของระบบกระดูกและกล้ามเนื้อเท้าและเข่าที่เกิดจากการประกอบอาชีพของชาวนาโดยพื้นฐานจากกายอุปกรณ์ของบุคคลที่มีสมองพิการ

ในงานวิจัยนี้คณะผู้วิจัยดำเนินการศึกษาเพื่อตรวจสอบอาการและสาเหตุของความผิดปกติของกระดูกและกล้ามเนื้อและสภาพความพิการของรยางค์ส่วนล่างของผู้ป่วย CP ที่มีโรคสมองพิการชนิดหดเกร็งประเภท spastic diplegia (มีอาการของขา 2 ข้างหดเกร็งมากกว่าแขน) เพิ่มจากการศึกษาครั้งก่อนอีกเป็นจำนวน 24 คน (อายุ 13.4 ± 2.3 ปี) ผลจากการศึกษาพบว่าอาสาสมัครผู้ป่วย CP ส่วนใหญ่ มีอาการผิดปกติ การรับรู้การปวด และสาเหตุความเจ็บปวด ในลักษณะเช่นเดียวกับการศึกษาเบื้องต้น และสอดคล้องกับผลการศึกษาในชานาในการศึกษาครั้งก่อน ผลการเปรียบเทียบของชานาและอาสาสมัครผู้ป่วย CP เป็นการยืนยันให้เห็นว่าประชากรทั้งสองสามารถเชื่อมโยงกันเช่นเดียวกับการศึกษาเบื้องต้นที่ผ่านมา นอกจากนี้ผลการศึกษาของการทดลองเพิ่มเติมเพื่อเปรียบเทียบกิจกรรมของกล้ามเนื้อระหว่างขณะที่ชานาเดินบนพื้นแข็งและพื้นโคลนแสดงให้เห็นว่า การเดินพื้นดินโคลนทำให้ระดับของกล้ามเนื้อต้นขาด้านหลัง (biceps femoris ที่ใช้ในการงอเข่า) และ กล้ามเนื้อน่อง (gastrocnemius ที่ใช้ในการงอข้อเท้า) มีค่ามากกว่าการเดินพื้นแข็ง ดังนั้นปัญหาระบบกระดูกและกล้ามเนื้อและความบกพร่องที่เท้าและเข่าจึงเป็นส่วนสำคัญที่ควรเน้นต่อการพัฒนาออกแบบเทคโนโลยีอำนวยความสะดวกเพื่อป้องกันความเสี่ยงต่อการบาดเจ็บรยางค์ส่วนล่างของทั้งชานาและผู้ป่วย CP

การทบทวนวรรณกรรมเกี่ยวกับเทคโนโลยีกายอุปกรณ์ของผู้พิการ พบว่าอุปกรณ์รองรับเท้าและข้อเท้าที่มีความยืดหยุ่นและแผ่นเสริมพื้นรองเท้าเป็นเทคโนโลยีที่เป็นไปได้ในการช่วยเหลือชานาในกระบวนการเพาะปลูกข้าว โดยพอลิเมอร์ชีวภาพและยางพาราเป็นวัสดุที่มีความเป็นไปได้ในการผลิตเทคโนโลยีอำนวยความสะดวกสำหรับชานา จากการทดสอบเชิงกลและเชิงเคมีพบว่าอัตราส่วนพอลิเมอร์ชีวภาพต่อยางพาราที่เหมาะสมต่อการใช้งานในสภาพพื้นที่ที่เป็นโคลนได้แก่ 3:2 ส่วนผสมของวัสดุดังกล่าวได้นำมาพัฒนาเป็นต้นแบบของเทคโนโลยีอำนวยความสะดวกในรูปแบบของรองเท้า ประกอบกับแผ่นเสริมเท้าซึ่งออกแบบโดยใช้เทคโนโลยีการสแกนเท้าและสร้างต้นแบบอย่างรวดเร็วเพื่อแก้ไขอาการผิดปกติของการหมุนของเท้าของแต่ละบุคคล การทดลองเพื่อเปรียบเทียบกิจกรรมของกล้ามเนื้อระหว่างการจำลองการดำนาโดยไม่ใส่รองเท้า ใส่รองเท้าบูท และใส่ต้นแบบของเทคโนโลยีอำนวยความสะดวกในรูปแบบของรองเท้า โดยมีอาสาสมัครที่มีอาการผิดปกติของ foot pronation พบว่าเทคโนโลยีอำนวยความสะดวกในรูปแบบของรองเท้าทำให้การใช้งานกล้ามเนื้อ gastrocnemius มีค่าน้อยที่สุด และลดการใช้งานของกล้ามเนื้อ biceps femoris เมื่อเทียบกับการใส่รองเท้าบูท ในขณะที่ยกเท้าออกจากพื้นดินโคลน นอกจากนี้เทคโนโลยีอำนวยความสะดวกในรูปแบบของรองเท้าสามารถช่วยให้กล้ามเนื้อที่หน้าแข้งด้านหน้า (Tibialis Anterior ที่ใช้ในการชะลอการเกิด pronate ของเท้า) มีค่าน้อยที่สุดในขณะยืนบนพื้นโคลน ดังนั้นเทคโนโลยีอำนวยความสะดวกในรูปแบบของรองเท้าที่เสนอในงานวิจัยนี้จึงมีความเป็นไปได้ที่จะสามารถลดและป้องกันความเสี่ยงต่อการบาดเจ็บรยางค์ส่วนล่างของชานาในการประกอบอาชีพได้

Previous research indicates congenital disabilities may have similar physical and cognitive outcomes to circumstantial disabilities encountered by workers in occupational tasks. There have been a number of studies conducted on assistive technology (AT) design for persons with disabilities that can be also applied to healthy workers who function in extreme environments. Our previous studies (previously funded by the Thailand Research Fund (TRF)) preliminarily identified correspondences between physical conditions of agricultural workers (rice farmers) and persons with congenital or disease-related disabilities (cerebral palsy (CP)). The studies found the farmers and CP participants to be potentially associated in terms of: foot pronation and knee valgus prevalence; knee pain perception and; foot and knee musculoskeletal impairments related pain. Through our previous studies, designing dual-use AT for working populations with MSDs and disabled populations was proved to be possible. This study aims to develop and preliminarily test a prototype of novel AT to target specific physical conditions and MSDs of knees and feet for rice farmers based on technology for CP populations.

In this study, we conducted additional examination of symptoms and causes of musculoskeletal and disability conditions of lower extremity (LE) in 24 CP patients (age: 13.4 ± 2.3 years) with spastic diplegia. In line with previous preliminary results of the CP and farmer investigation, CP participants were found to exhibit similar characteristics of deformity, pain perception and origin of pain. The comparison results of farmers and CP participants confirmed the association between two populations, as previously identified in our preliminary study. Moreover, results of additional experiment, comparing muscle activity between when farmers walking on rigid and muddy ground, showed muddy ground to induce significantly higher levels of biceps femoris (BiF; knee flexor) and gastrocnemius (GA; ankle plantar flexor) muscle exertion, as compared with rigid ground. Therefore, knee and foot impairments and MSDs were emphasized in the development of our AT designs to prevent risk of LE injury for both farmer and CP populations.

The reviews of current orthotic technologies indicated a flexible ankle-footwear with corrective insoles to be a possible intervention to farmers in rice cultivation work. Biopolymer and natural rubber were selected as potential materials for AT design for farmers. Based on mechanical and chemical property tests, the ratio of biopolymer to rubber that was suitable for use in muddy areas was 3:2. The mixture of such materials was then developed as a prototype of AT in a form of footwear. The AT was equipped with corrective insoles designed using foot scanning technology and rapid prototyping to provide individual correction of foot

deformation. Experimental study was conducted with participants with foot pronation to compare muscle activity during simulated planting task with: barefoot, wearing common boots and wearing AT footwear. Results showed that during lifting the feet off the muddy ground, the AT footwear required the lowest levels of GA muscle exertion and lower levels of BiF muscle, as compared with wearing common boots. In addition, the AT footwear induced the lowest levels of tibialis anterior (TA; used to decelerate foot pronation) while standing on the mud. Therefore, the AT footwear proposed in this research provided a potential intervention for reducing and preventing risk of LE injury for farmer in their occupational tasks.

Keywords : Assistive technology; circumstantial disability; congenital disability; musculoskeletal conditions

(คำหลัก) เทคโนโลยีอำนวยความสะดวก; ความพิการอันมีผลเนื่องมาจากสถานการณ์; ความพิการแต่กำเนิด; สภาพระบบกระดูกและกล้ามเนื้อ

1. Executive summary

Previous research indicates congenital disabilities may have similar physical and cognitive outcomes to circumstantial disabilities encountered by workers in occupational tasks. The nature of certain work environments results in healthy workers having performance comparable to a disabled population. There have been a number of studies conducted on assistive technology (AT) design for persons with disabilities that can be also applied to healthy workers who function in extreme environments. Therefore, studying non-occupational disabilities can be used as a basis for AT design for occupational persons since AT designs for the former population are common (e.g., back braces, foot orthotics, leg braces, etc.) and are ubiquitous in the commercial market. Whereas, technological intervention designs for preventing worker disadvantage in extreme conditions are limited.

This project is motivated by prior collaborative research between the faculties of Production Technology and Physical Therapy at Khon Kaen University (KKU) with partners in industrial engineering at North Carolina State University (currently moved to University of Florida) and physical therapists at the University of North Carolina at Chapel Hill (funded by the Thailand Research Fund (TRF)). The study preliminarily identified correspondences between foot and knee musculoskeletal disorders (MSDs) of agricultural workers (rice farmers) due to repetitive strain injuries (RSIs) with musculoskeletal conditions of persons with congenital or disease-related disabilities (cerebral palsy (CP)). Through our previous studies, designing dual-use AT for working populations with MSDs and disabled populations towards improving ergonomics in work and daily living tasks was proved to be possible. This study aims to develop and preliminarily test a prototype of novel AT to target specific physical conditions and MSDs of knees and feet for rice farmers based on technology for CP populations. The new AT design may be slightly different for use in rice farmers and CP patients due to objective and usage environment differences.

In this study, additional examination of symptoms and causes of musculoskeletal and disability conditions of lower extremity (LE) was conducted in 24 CP patients (age: 13.4 ± 2.3 years) with spastic diplegia. Results showed participants perceived greater pain in knee and hip, as compared with foot region. However, malalignment examination indicated the

prevalence of LE characteristics was found to be highest in knee valgus (83.3%) and foot pronation (75.0%). Origin of pain was mainly found at knee joints and LE muscles. The findings were also in line with results of previous farmer investigation. Therefore, the musculoskeletal and disability conditions of the two populations were confirmed to be mapped to each other in terms of symptoms (malalignment and pain perception) and causes (origin of structural damage). In addition, the environment condition of muddy work terrain may also increase force on LE joints and muscles due to adverse effects of ground viscous force on legs and feet. Results of additional experiment, comparing muscle activity between when farmers walking on rigid and muddy ground, showed muddy ground to induce significantly higher levels of biceps femoris (BiF; knee flexor) and gastrocnemius (GA; ankle plantar flexor) muscle exertion, as compared with rigid ground. Therefore, knee and foot impairments and MSDs were emphasized in the development of our AT designs.

The reviews of current orthotic technologies indicated a flexible ankle-footwear with corrective insoles to be a possible intervention to farmers in rice cultivation work. Biopolymer and natural rubber were selected as potential materials for AT design for farmers. Mechanical and chemical property tests were conducted to find the best proportion of biopolymer-rubber composite when working with a specific muddy environment of rice cultivation. Results showed a suitable ratio of biopolymer to rubber to be 3:2. The mixture of such materials was then developed as a prototype of AT in a form of footwear. The AT was designed to be equipped with corrective insoles, which developed using foot scanning technology and rapid prototyping to provide individual correction of foot deformation.

The proposed design for novel AT for farmers was subsequently assessed using ergonomic measurement methods in laboratory mock-ups of rice planting tasks. Experimental study was conducted with participants with foot pronation in order to compare LE muscle activity during simulated planting task with 3 conditions, including: barefoot, wearing common boots and wearing AT footwear. Results showed that during lifting the feet off the muddy ground, the AT footwear required the lowest levels of GA muscle exertion among all conditions, and required lower levels of BiF muscle, as compared with wearing common boots. In addition, the AT footwear induced the lowest levels of tibialis anterior (TA; used to decelerate foot pronation) while standing on the mud. Therefore, the AT footwear proposed in this research provided a potential intervention for reducing and preventing risk of LE injury for farmer in their occupational tasks. This research can be used as a basis for designing dual-

use AT with applicability across the farmers and CP populations towards improving ergonomics in work and daily living tasks.

2. วัตถุประสงค์ของโครงการ

The results of the research are expected to be transformative with respect to disability engineering research on the design and development of occupational AT based on congenital disability assistive devices. The proposed project will address the following objectives:

(a) Formulate extensive mapping of physical conditions in farmers to congenital disabilities of CP patients;

(b) Design low-cost, highly usable AT prototypes for assisting farmers in extreme environments and reducing ergonomic risk exposure during planting tasks based on ATs for congenital disabled CP persons;

(c) Preliminarily conduct empirical evaluation of ATs using high-fidelity lab mock-ups of work tasks; and

(d) Provide dual-use potential of the design interventions for assisting farmers in extreme environments and reducing ergonomic risk exposure, as well as supporting and improving CP patients' daily living tasks.

Figure 1 presents a diagram of the previous findings of correspondences of symptoms, causes and musculoskeletal impairment risk factors for CP patients and rice farmers as a basis for design and prototyping of novel AT for both populations in this project. The results of the research are expected to be transformative with respect to disability engineering research on the design and development of dual-population AT.

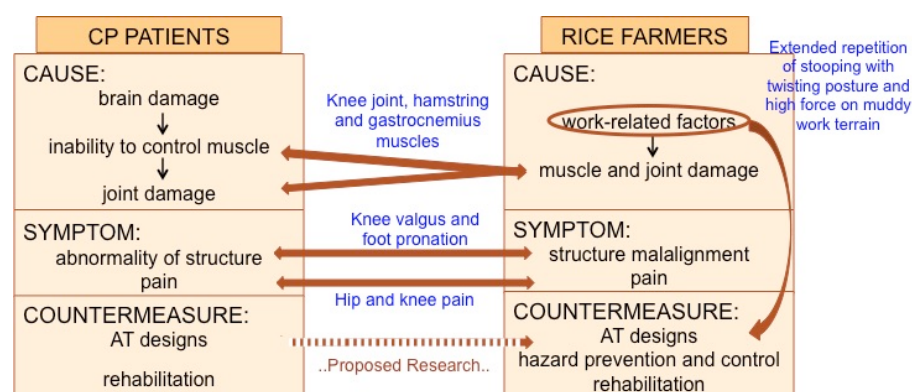


Figure 1. Overall findings in previous studies as a basis for the proposed research

3. ระเบียบวิธีวิจัย

3.1. Participants

Twenty-four CP patients were recruited for the first phase (survey phase) of this study. CP participants (12 male and 12 female patients with age > 12 years) with spastic diplegia were recruited from the Srisangvalya Khon Kaen School for children with special needs and the Physical Rehabilitation Center of Saint Louis Hospital in Bangkok. CP patients participated in this study would have had no surgeries on their LEs within the 12 months prior to enrollment in the study. Participants also had LE pain that is related to knee and foot mechanics.

A small number (9) of farmers, who exhibits foot pronation condition, were recruited for participating in the last phase (experimental phase) of the study. This sample size estimated based on previous customized orthoses testing for disabled population, in which sample size ranged from 9-70 subjects (Branthwaite et al., 2004; Chen et al., 2003). Experienced rice farmers (4 male and 5 female farmers with age between 20-59 years) in rice farming villages located in Sawathee district, Khon Kaen Province, were recruited to participate in the study. Participants were required to have at least one year of experience in rice planting process. All participants had no current injury to the LEs or any previous history that would affect LE alignment, such as a fracture and/or surgery. Participants were excluded from the study if they have had chronic leg and foot pain within two weeks prior to testing, such as gouty arthritis, rheumatoid arthritis, or ankylosing spondylitis.

3.2. Methods

Participants were asked to read and sign a consent form that had been approved by the human ethics committee of Khon Kaen University (for farmer study) and Saint Louis College (for CP study) before participation. The studies were done separately between rice farmers and CP participants. The scope of this research will include 6 sub-studies as illustrated in Figure 2. The details of each study were described as followed:

The clinical measures of LE alignment and structural associated with pain were conducted by licensed and expert physical therapists. LE alignment characteristics examined in this study included pelvic angle, femoral antetorsion, quadriceps (Q) angle, tibiofemoral angle, genu recurvatum, tibial torsion, rearfoot angle, and medial longitudinal arch angle. An assessment of the LE region was conducted to identify the common musculoskeletal impairments related to pain including dysfunction of the joint, neural tissue and muscle. All measurements were repeated 3 times.

3.1.2. Study 2: Reviews of current orthotic technologies for AT design for farmers

Based on interventions that have been applied for CP patients (e.g., Novak et al., 2013), we have reviewed and identify types of assistive technology that may be applicable for rice farmers including, molded limb orthoses, removable external orthotic devices, corrective insoles, and breathable orthotic garments.

Although detailed reviews indicated molded orthoses have been successfully enhanced range of motion (ROM) of the lower limbs (Autti-Ramo et al., 2006; Blackmore et al., 2007), they also have some adverse effects. Plaster casts orthoses are expensive, time consuming to produce and difficult to fit into footwear (Chapman, 1999; Stell & Buckley, 1998). Other reported adverse effects of casting included: skin irritation (Glanzman et al., 2004; Corry et al., 1995; Blackmore et al., 2007; Cottalorda et al., 2000), foot and calf pain (Corry et al., 1998; Cottalorda et al., 2000), cast breakdown (Watt et al., 1986), continuing impairment conditions (Blackmore et al., 2007; Glanzman et al., 2004), and difficulty bathing (Flett et al., 1999).

Removable external orthotic devices, such as knee braces, ankle foot orthoses (AFO) and knee ankle-foot orthoses (KAFO), are generally used to control movement, provide an opposing force, and support ineffective joints or muscles (Brouwer et al., 2005). However, conventional rigid designs have a functional disadvantage as the restriction of movement causes significant reduction in flexion during the swing phase (Rethlefsen et al., 1999; Thomas et al., 2000; Richards et al., 2005) as they provide stability during walking by keeping the knee and ankle in a fixed position during the complete gait cycle (Yakimovich et al., 2009). More recent designs include adaptive control for joint restriction using pneumatic or electric actuators, for example, a powered lower limb orthosis with electrical motor and locking system (Font-Llagunes et al., 2012), robot-assisted lower limb orthosis (Meyer-Heim and van Hedel, 2013; Byl, 2012) and, joint active system ankle orthosis (Costa et al., 2012). However, the costly

and complicated systems and the need of an external power source is the main drawback (Cullell et al., 2009).

Simple corrective insoles are less expensive and can be used to reduce foot eversion in footwear that has restricted space (Branthwaite et al., 2004). Previous research showed corrective simple insoles to reduce a maximum eversion of 3.1° (Branthwaite et al., 2004). A 5° wedge insert was successfully tested for the treatment of flexible flatfoot (Chen et al., 2003). It was estimated that simple insoles can be manufactured with 2.5 times cheaper and 3 times faster, as compared molded orthotics (McCourt, 1990).

Breathable orthotic garment, such as TheraSuit (Alagesan and Shetty, 2011; Bailes et al., 2011), lycra garments (Rennie et al., 2000; Nicholson et al., 2001; Knox, 2003), and Adeli suit treatment (Bar-Haim et al., 2006), is another possible intervention that found to help improve gross motor function. There are no serious safety events or skin abrasions reported during the treatment using the lightweight orthotic garments (Bailes et al., 2011). The suit is also designed to wear with bungee cords; however, the additional cords did not add any benefit when comparing with wearing the suit alone (Bailes et al., 2011). Therefore, it might be a possible intervention to farmers in field work.

3.1.3. Study 3: Reviews and test of potential materials for AT design for farmers

The ATs are designed using various types of materials, including metal structure with leather upholstery, alloy plate combined with biodegradable plastics and, metal/polymer custom molded to the lower limb shapes (Yakimovich et al., 2009; Alam et al., 2015). Among these materials, polymer, in both natural and synthetic forms, has been primarily used to manufacturing AT for neurological disorder patients (e.g., Hsu et al., 2007; Mavroidis et al., 2011; Telfer et al., 2010). In Thailand, natural rubber is one of the major economic products. Natural rubber has excellent mechanical properties such as high elasticity property, tensile strength, and tear resistance (Sae-oui et al., 2007). Chemical compositions of fresh natural rubber latex comprise of cis-1,4-polyisoprene (rubber particles) in the range of 35 - 42%, water in the range 58 - 60%, protein in the range 2 - 3%, sterol glycosides in the range 0.1 - 0.5%, resins in the range 2.5 - 3.5%, ash in the range 0.5 - 1.0%, and sugars in the range 1.0 - 2.0% (Kuntanoo et al., 2015b). However, it has disadvantages of low oil resistance, air permeability, ozone resistance, compression set, and thermal aging resistance (Jovanovic et al., 2018; Witinuntakit et al., 2018; Sae-oui et al., 2007). Due to these weaknesses, natural rubber is commonly mixed with other synthetic rubbers or polymers (Sae-oui et al., 2007).

Polyhydroxyalkanoates (PHAs) are promising natural polymers, with biodegradable and biocompatible properties (Kaewkannetra and Promkotra, 2013), that have been developed to successfully fulfill certain demands that required in both medical and industrial sectors (Abou-Zeid, 2001). The PHAs are naturally synthesized from renewable sources, made using microbial process on sugar-based medium, where they work as carbon and energy storage materials (Kuntanoo et al., 2013). Polyhydroxybutyrate-co-hydroxyvalerate (PHBV) is one of PHAs sub-group member, making by many microorganisms and achieved good biodegradability (Kuntanoo et al., 2015b). However, a drawback of PHBV is too rigid, brittle and lack of superior mechanical properties (Kuntanoo et al., 2013). This weakness limits the PHBV for advanced application. It is possible to improve the PHBV by making some modifications on its mechanical property, such as chemical modification or physical blending. The blending process is preferred due to fast, simple, and low cost working method (Weng et al., 2010). Kuntanoo et al. (2015a) successfully improved the properties of PHBV by mixing with natural rubber. The elasticity of natural rubber can eliminate the disadvantage properties of PHBV. The reviews and previous work on materials indicated the natural rubber mixed with PHBV to have promising properties of high elasticity, tensile strength, tear resistance, and biocompatibility. Therefore, we and our partner, Dr. Sarunya Promkotra (Geotechnology, KKU), adopted this PHBV copolymer and natural rubber for AT development.

Concentrated researches related to filler types is to develop the mechanical properties of elastomeric materials as natural rubber, such as carbon nanotubes, carbon black, and some clays (Jovanović et al., 2013; Le et al., 2015). Another substance for blending in natural rubber is vegetable oils (Richtler and Knaut, 1983; Nandan et al., 1997; Kundu, 2000). They have plenty of free fatty acids which are useful for mixing in rubber compounds. Vegetable oils behave as a coupling agent for development of rubber-filler interaction in carbon black (Kundu, 2000). One of vegetable oils is coconut oil which contains high saturated fat content or fatty acid, known as medium chain triglycerides, such as lauric acid, capric acid, caprylic acid, and caproic acid. However, this coconut oil is still contained a small amount of long chain triglycerides. To improve physical properties of PHBV and natural latex blends, coconut oil was selected to be an additive in a natural latex composition containing the oil-extended latex rubber as a component.

The natural latex rubber was obtained from The Rubber Authority of Thailand: Rubber Learning Center Khon Kaen Province. The creamy liquid latex rubber was kept in a refrigerator in 4–6° C. The native pH of field latex is around 7.0 with a density between 0.9 and 0.98

(Blackley, 1997). However, the pH decreases with the storage indicating less stability of the rubber (Ho, 1989). The isoelectric pH of the natural rubber latex particles is estimated to be between 4 and 4.7 (Ho et al., 1996). At the isoelectric pH, the protein becomes unstable. A pH measurement was initially conducted for determining the pH of rubber before mixing with PHBV. PHBV dissolved in chloroform solution (P) (2% and 3% w/v) was first agitated with coconut oil at room temperature. Subsequently, these mixtures of PHBV and coconut oil (virgin (VC) and cooking (CC)) were vigorously blended with the natural latex (L) in three different portions including, ratios of 3:2, 1:1, and 2:3 (P:L), and controlled the temperature at 50°C during mixing. According to Kuntanoo et al., (2015a) and Promkottra and Kangsadan (2015), these three ratios gave the best results in terms of morphological-based and mechanical properties results. After energetic blending, shaping biopolymeric films were shaped with extruder and dried at 50°C for 3 days in the oven.

Thermal characteristics of these biopolymer products were examined by the differential scanning calorimetry (DSC), based on ASTM E794 – 06 (Standard Test Method for Melting and Crystallization Temperatures by Thermal Analysis). The DSC results revealed certain aspects of melting temperature (T_m), enthalpy (ΔH), and crystallinity (%). Mechanical test was performed by using Universal Testing Machine (UTM, Instron 5567A). Specimen size measuring referred to ASTM D882-10 with a rectangular shape of specimens, dimension specifications as 100 mm in total length, 20 mm width, and 50 mm in gauge length (benchmark). Thickness of the specimen was closely to 1.0 mm. Three specimens of each composite film were tested for calculating the average of a set of tensile data. Before the test, the specimens were held tightly with pneumatic grips and controlled a crosshead speed of 5 mm/min. Lastly, an investigation of effect of mud viscous force to varied formula of composites was performed by examining force differences between dry specimens and specimens immersed in mud.

3.1.4. Study 4: Investigation of effects of muddy work terrain

Since most rice cultivation tasks were performed in muddy terrain, we also investigated an additional experiment to compare muscle activity between when 30 experienced farmers (15 males and 15 females) walking on rigid and muddy ground. The experimental mud samples were prepared in an 85 cm x 120 cm tray filled with a mud layer height of 18 cm. The height of the layer was based on the average immersion depth of farmer's legs in the mud (13 cm) retrieved from previous measurements conducted directly in the rice field (Juntaracena and

Swangnetr, 2016), and extended by an additional 5 cm to compensate for any possible variations. Electromyography (EMG) electrodes were placed over the right side of the subject's LE muscles, including rectus femoris (RF; part of the quadriceps group), biceps femoris (BiF; part of the hamstring group) and gastrocnemius (GA). The muscle selection was based on LE joint angles during gait initiation in specific rice planting tasks affected by mud viscous force.

The participants were asked to perform the simulated rice planting task at 2 conditions (see Figure 4): 1) No-Force condition (rigid surface) and; 2) Mud-Force condition (muddy surface). In both experimental conditions, participants were asked to carry a bundle of wood sticks, simulating rice sprouts with a typical weight force of 3 kg, in the left hand and 0.3 kg (weight force of one tenth of a bundle) in the right hand. Muscle activity was captured using EMG during a 10-session simulated planting task.

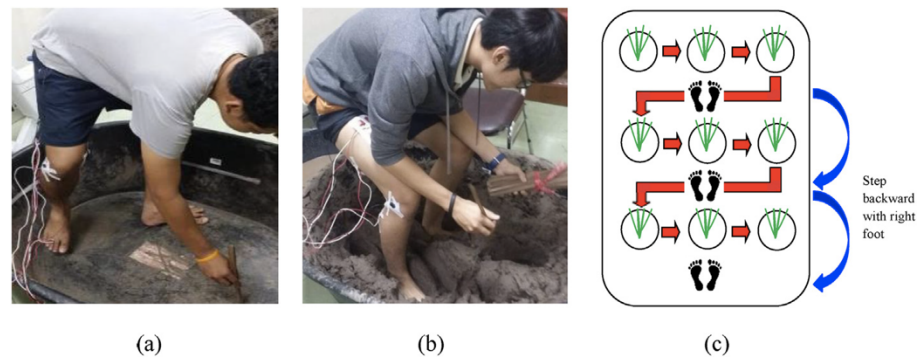


Figure 4. Simulated planting task performance: (a) No-Force condition; (b) Mud-Force condition; (c) direction of movement.

3.1.5. Study 5: AT design and prototype

Proposed AT design was based on the reviews of current orthotic technologies and potential materials. The design of pronate foot correction was developed based on literatures and recommendations from our partner, Dr. Gross, an expert physical therapist who has been working with patients with foot deformity for more than 30 years. The AT designs and prototypes were customized for individual farmer participants.

3.1.6. Study 6: Investigation of effects of proposed AT

Last part of the study included an investigation a small number (9) of farmers with foot pronation. The experiment was to compare muscle activity when experienced farmers performing a simulated rice planting task on muddy environment with 3 conditions, including: 1) bare feet (BF); 2) using common footwear (CF); and 3) using proposed AT (AT). The

experimental setup and mud samples were prepared in the same ways as described in the Section 3.1.4. EMG electrodes were placed over the right side of the subject's LE muscles, including: BiF and GA associated with lifting the feet off the muddy ground and; tibialis anterior (TA; used to decelerate foot pronation) associated with standing on the mud.

4. ผลและอภิปรายผลการดำเนินงานของโครงการ

4.1. Study 1: Results of LE musculoskeletal conditions of CP patients

Average scores of pain ratings of each LE parts perceived by CP patients were showed in Table 1. The perceived pain of rice farmers (conducted in previous study) during planting performance was also illustrated for comparison purposes. It can be seen that both CP and farmer participants perceived greater pain in hips and knees, with less pain perception in feet.

Table 1. Perceived pain ratings of lower extremity parts for CP patients and farmers

Body part	CP patients	Farmers
Hip	1.96 (2.51)	6.51 (4.01)
Knee	1.83 (2.28)	4.02 (3.00)
Ankle/foot	1.75 (1.98)	1.74 (0.60)

For the prevalence of LE malalignment, the average of three alignment measurements was used for analyses. Table 2 presented a comparison between the prevalence of LE malalignment for CP participants observed in this study and rice farmers (conducted in previous study). Among LEs, foot pronation and knee valgus were found to be the highest prevalence, for both CPs and farmers. Other lower extremity malalignment included external tibial torsion, posterior pelvic tilt, femoral antetorsion, knee hyperextension, and knee varus. No anterior pelvic tilt and supinate foot conditions were observed in the studies.

The prevalence of lower extremity impairments related pain characteristics of CP patients and rice farmers (conducted in previous study) presented in Table 3. Physical examination of functional and diagnostic tests indicated that the origins of pain in both CP patients and farmers were due to impairments of knee joint and LE muscles.

Table 2. Prevalence of lower extremity malalignment for CP patients and farmers

Characteristics	Malalignment (%)	
	CP patients	Farmers
Posterior pelvic tilt	58.33	30.52
Excessive femoral antetorsion	66.67	28.11
Knee valgus	83.33	34.94
Knee varus	37.50	30.92
Knee hyperextension	29.17	11.24
External tibial torsion	45.83	21.29
Foot pronation	75.00	36.14

Table 3. Prevalence of lower extremity impairments for CP patients and farmers

Origin of pain	Musculoskeletal impairment (%)	
	CP Patients	Farmers
Joint		
• Hip	41.67	22.18
• Knee	70.83	54.61
• Ankle and foot	62.50	5.12
Muscle		
• Hip	50.00	30.38
• Knee	62.50	36.18
• Ankle and foot	75.00	26.28
Neural tissue	0	26.62

This study found the highest prevalence of LE was foot pronation and knee valgus. Both CPs and farmers perceived highest hip pain among all lower limb regions. Although both populations experienced less knee and foot pain during daily activities and cultivation activities, malalignment examination results indicated higher prevalence in foot pronation and knee valgus. Excessive foot pronation may also originate from other malalignment conditions, including excessive internal femoral rotation, external tibial rotation or anterior pelvic tilt position (Khamis and Yizhar, 2007; Barwick et al., 2012), which might contribute to hip muscle pain (Chuter et al., 2012). The structural origin of pain in both populations was

also found at the knee joints and LE muscles. Therefore, the musculoskeletal and disability conditions of the two populations were confirmed to be mapped to each other in terms of symptoms (malalignment and pain perception) and causes (origin of structural damage).

4.2. Study 2: Results of orthotic technologies for AT design for farmers

Based on the reviews, it can be seen that simple corrective insoles and lightweight orthotic garment are possible orthotic technologies to be used as a basis for designing interventions for farmers in field work. The collected results from Study 1 revealed knee and foot to be priority LE parts for AT development. However, foot pronation and knee valgus are linked deformities. Foot pronation will drive medial collapse of the entire LE and move the knee in the direction of valgus deformity. Therefore, controlling foot pronation might not only address foot and ankle issues, it might also decrease the valgus loading at the knee. Therefore, we decided to develop a flexible and lightweight ankle-footwear with corrective insoles for assisting farmers' feet on rice cultivation performance.

4.3. Study 3: Results of materials for AT design for farmers

The formulation of the blends presents in Table 4. Three components with several concentrations and the mixing ratios were varied in two series.

Differential Scanning Calorimetry (DSC)

Thermograms attained from the first heating scan for the PHBV-Latex biocomposites (P-L), and PHBV-Latex-Coconut oil (P-L-C) blends are shown in Figure 5. Melting temperature (T_m) and enthalpy were obtained from the first heating scan. The degree of crystallinity of blends was calculated by computing the heat associated with melting (fusion) of these composites. This heat was stated as crystallinity in percent by normalizing with respect to the fusion heat of a 100 % PHBV crystalline sample, as indicated in Equation (1).

$$\text{Degree of crystallinity} = (\Delta H_f - \Delta H_c) / \Delta H_{f, 100\%} \times 100\% \quad (1)$$

where ΔH_f is the enthalpy of melting, ΔH_c is the enthalpy of crystallization, and $\Delta H_{f,100\%}$ is the enthalpy of melting for a fully PHBV crystalline polymer based upon 55.40 J/g.

Table 4. Formula of PHBV-Latex-Vegetable oil composites which vegetable oil is virgin coconut oil (VC) and cooking coconut oil (CC)

Item	PHBV-L-C (2% w/v)	PHBV-L-C (3% w/v)
1	2P3-L2	3P3-L2
2	2P1-L1	3P1-L1
3	2P2-L3	3P2-L3
4	2P12-L8-VC1	3P12-L8-VC1
5	2P10-L10-VC1	3P10-L10-VC1
6	2P8-L12-VC1	3P8-L12-VC1
7	2P6-L4-VC1	3P6-L4-VC1
8	2P5-L5-VC1	3P5-L5-VC1
9	2P4-L6-VC1	3P4-L6-VC1
10	2P12-L8-CC1	3P12-L8-CC1
11	2P10-L10-CC1	3P10-L10-CC1
12	2P8-L12-CC1	3P8-L12-CC1
13	2P6-L4-CC1	3P6-L4-CC1
14	2P5-L5-CC1	3P5-L5-CC1
15	2P4-L6-CC1	3P4-L6-CC1
16	PHBV	
17	Rubber	

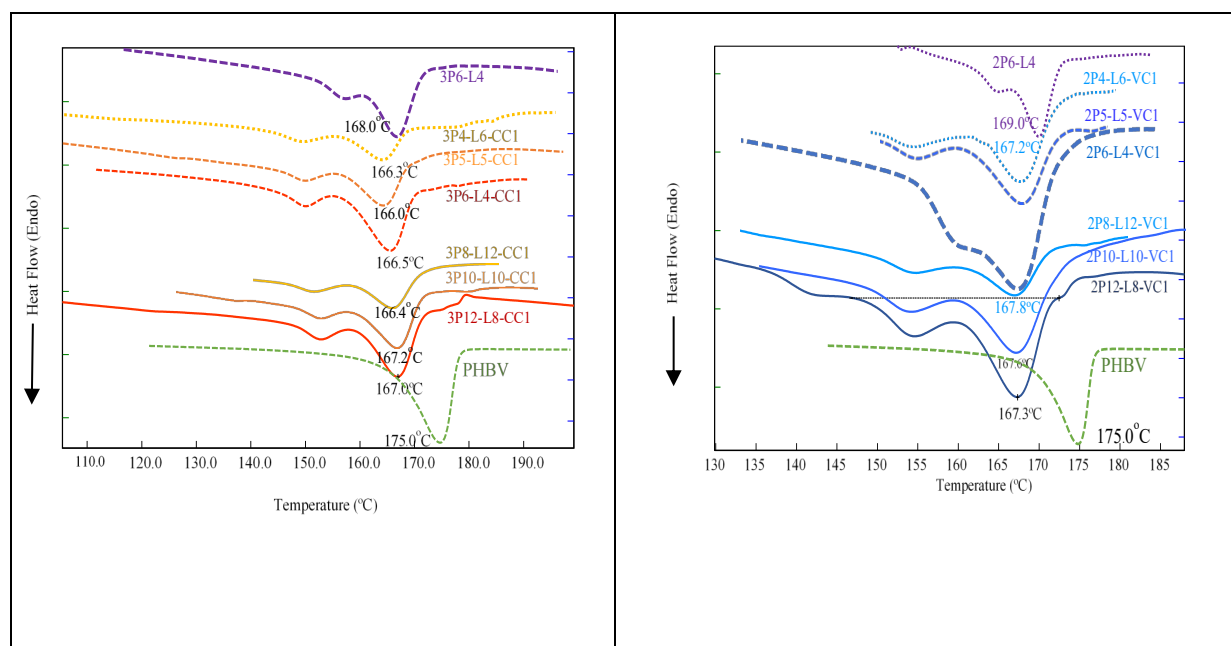


Figure 5. Melting endotherms for biopolymer films in different compositions of PHBV-Latex-Coconut oil (Px-Lx-Cx) by vary the concentrations of PHBV (2%, 3% w/v)

The coconut oil mixes showed a lower melting temperature (166-167°C) compared to the mixture without coconut oil (xPx-Lx) (168-169°C) (Figure 6). For 3Px-Lx-C1 compositions, an increase proportion in both virgin- and cooking coconut oil produced lower melting points for about 1.0-1.5°C. Results showed overall degree of crystallinity for the 3% w/v of PHBV blends (3Px-Lx-Cx) to be higher than the 2% w/v of PHBV blends (2Px-Lx-Cx), except for the series of 2P6-L4-VC1 and 2P5-L5-VC1 (Figure 7). In general, the virgin coconut oil mixes indicated the physical properties of a poor inconsistency of T_m , enthalpy, and degree of crystallinity.

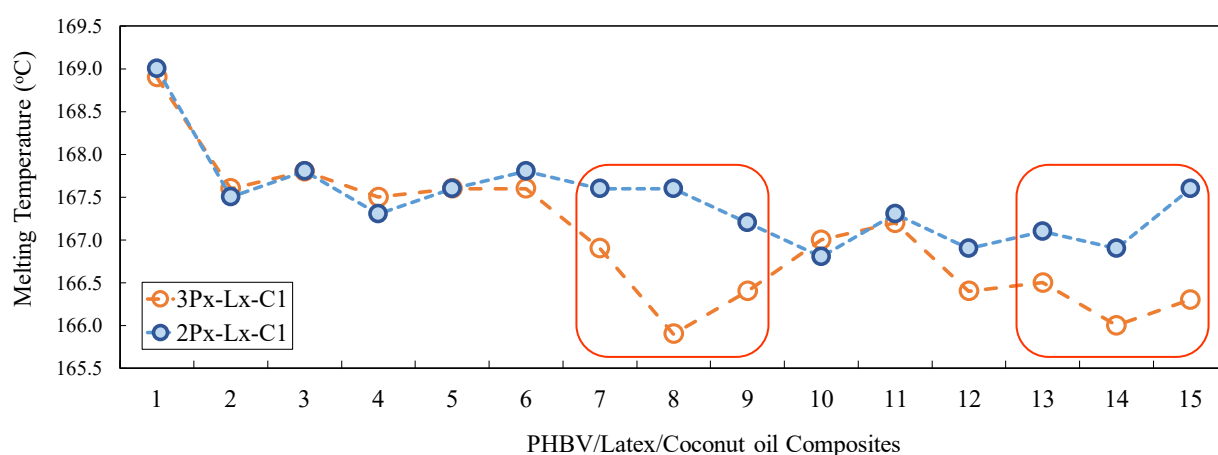


Figure 6. Melting temperature related to the composite materials of PHBV-Latex-Coconut oil in different mixing ratio, corresponding to Table 4

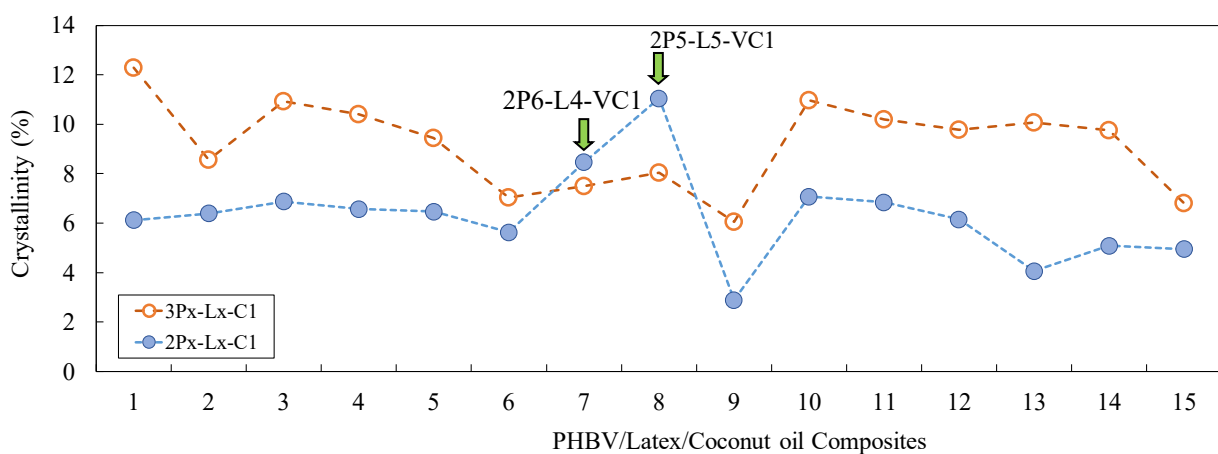


Figure 7. Crystallinity (%) related to the composite materials of PHBV-Latex-Coconut oil in different mixing ratio, corresponding to Table 4

Tensile Testing

The addition of the coconut oil to the 2% w/v PHBV-Latex matrix resulted in a 10% increase in tensile modulus, as compared to the 3% w/v PHBV-Latex matrix, especially for cooking coconut oil (CC) of 2P12-L8-CC1 (Figure 8). However, there were very important

variations in the tensile elastic modulus and yield strength for the 2% w/v PHBV-Latex-Virgin coconut oil (2Px-Lx-VC1). The reason was that the virgin coconut oil has an extra 55% saturated fat, but the cooking coconut oil has nil. According to Figures 6-7, the degree of crystallinity increased in 3Px-Lx-C1, however, their melting temperatures presented lower values than those of 2Px-Lx-C1. The effect of low melting temperature obviously influenced to a reduction in modulus and yield strength of both 3Px-Lx-VC1 and 3Px-Lx-CC1 composites. The presents of the coconut oil in the blends attributed to conformity declaration of plastic deformation after yield until break, particularly the cooking coconut oil. Increase the amount of coconut oil twice to the PHBV-Latex matrix affected the short elongation at break of this composite and resulted in 50% faster in failures.

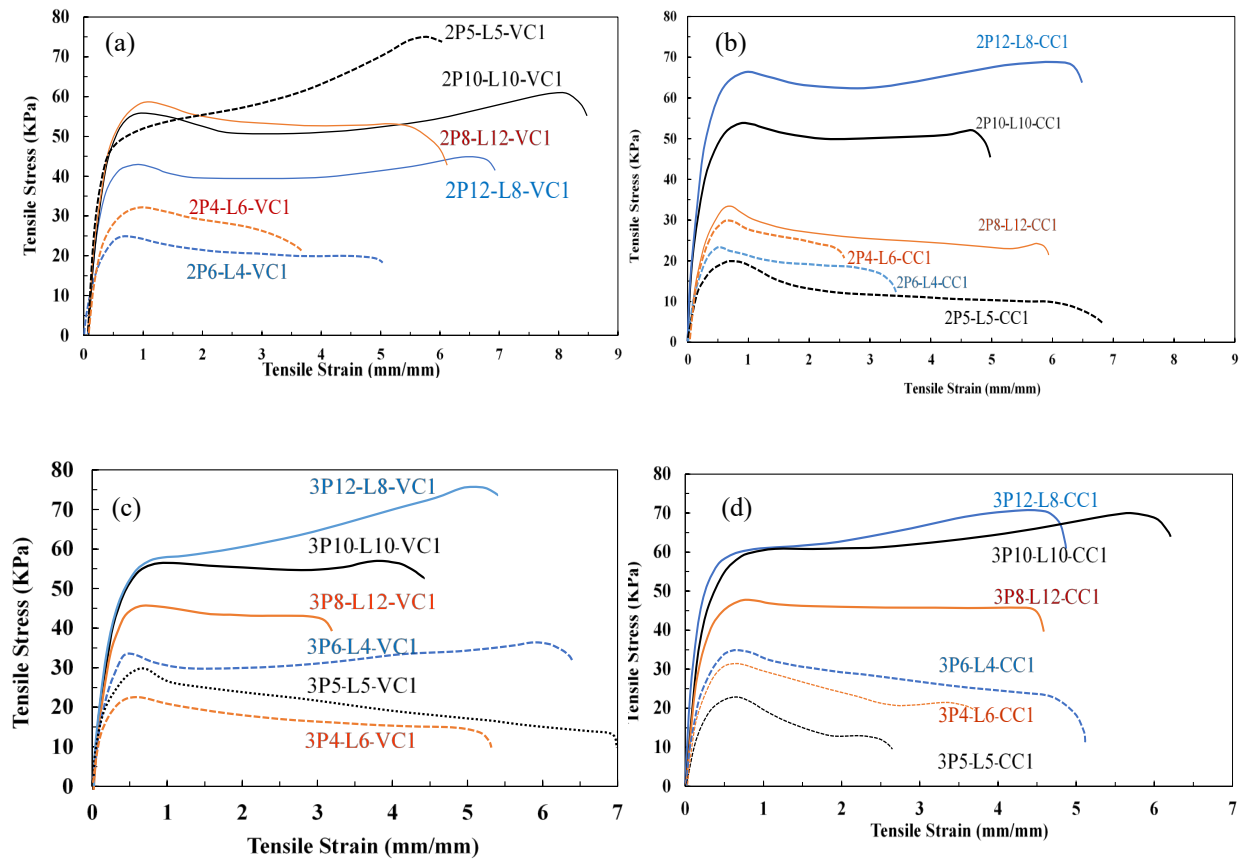


Figure 8. Tensile stress as a function of tensile strain of P/L samples in two PHBV concentrations (2% and 3% w/v of PHBV-2P, 3P) with the addition of virgin coconut oil (VC) and cooking coconut oil (CC) to the P/L components by two composition series in the ratio of (I)12:8:1, 10:10:1, 8:12:1, and (II) 6:4:1, 5:5:1, 4:6:1 (a) 2Px-Lx-VC1, (b) 2Px-Lx-CC1, (c) 3Px-Lx-VC1, and (d) 3Px-Lx-CC1

Compressive Testing

The addition of the coconut oil to the 3% w/v PHBV-Latex matrix resulted in a less shortening as compressive load increased, as compared to the 2% w/v PHBV-Latex matrix, especially for cooking coconut oil (CC) (Figure 9). The compositions of P6-L4-CC1 and P5-L5-CC1 indicated consistency physical properties of degree of crystallinity, which deformation of the 3% w/v of PHBV blends (3Px-Lx-Cx) was less than the 2% w/v of PHBV blends (2Px-Lx-Cx).

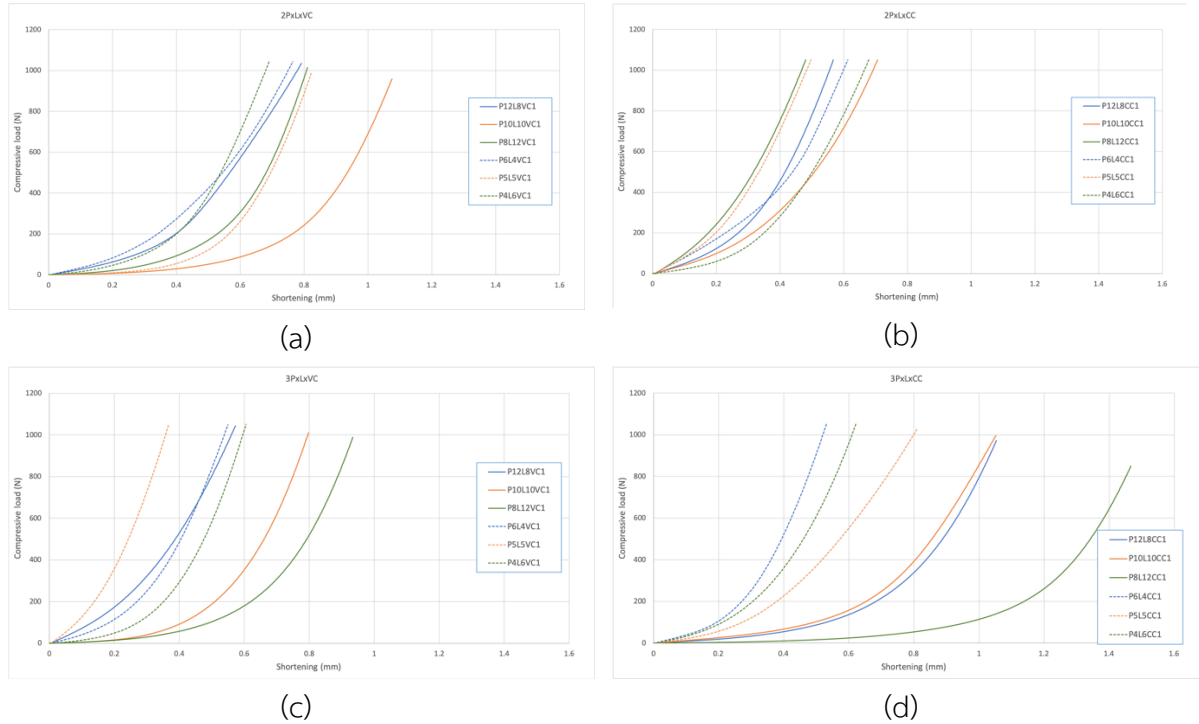


Figure 9. Compressive Load-shortening curves of P/L samples in two PHBV concentrations (2% and 3% w/v of PHBV-2P, 3P) with the addition of virgin coconut oil (VC) and cooking coconut oil (CC) to the P/L components by two composition series in the ratio of (I)12:8:1, 10:10:1, 8:12:1, and (II) 6:4:1, 5:5:1, 4:6:1 (a) 2Px-Lx-VC1, (b) 2Px-Lx-CC1, (c) 3Px-Lx-VC1, and (d) 3Px-Lx-CC1

Mud Viscous Force Test

Force differences between dry specimens and specimens immersed in mud are presented in Figure 10. Results showed all composites to induce less force resulted from mud adhering to specimen, as compared with rubber. Cooking coconut oil biopolymer-rubber composite presented a consistency trend, which 2Px-Lx-CC drew less mud than 3Px-Lx-CC. Virgin coconut oil mixes, although presented very little additional weight by some formulas, produced inexplicit trends.

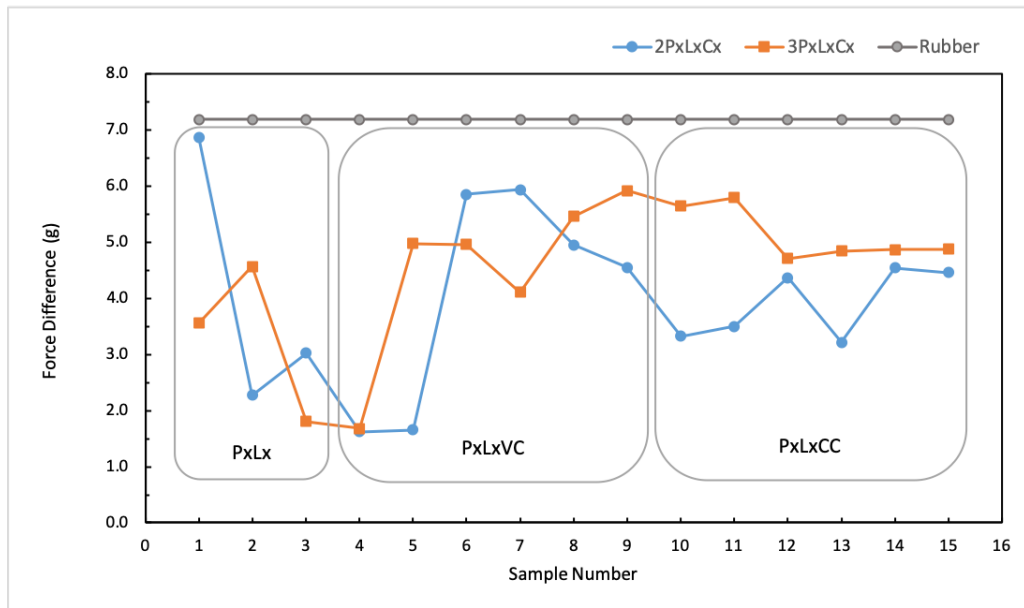


Figure 10. Force differences dry specimens and specimens immersed in mud

Material Composition Selection

A selection of composition of P/L/C composites were considered for 2 parts of the proposed AT.

- *Material composition for flexible and lightweight footwear shells:* a suitable material for footwear shells should pose acceptable yield strength to withstand tensile force from mud viscosity. Based on laboratory testing of the viscosity parameters using a Rotational Rheometer (Gemini 200Hr nano), the average viscosity property of the mud samples collected from rice planting site was 3.6 ± 0.22 kPa. Therefore, all composition would be able to endure mud tensile force. When considered the tensile modulus, it can be seen that 2% w/v PHBV-Latex matrix resulted in an increase in tensile modulus, as compared to the 3% w/v PHBV-Latex matrix, especially for adding cooking coconut oil as an additive. Among 2% w/v PHBV-Latex matrix, the 2P12-L8-CC1 was not only generated the highest yield strength, but also longest elongation at break. This property allowed the material to be manufactured into very thin sheets but still high shear resistance. Another aspect of a suitable material for footwear shells was to help reduce mud viscous force for wearer's legs. Results of force differences between dry specimens and specimens immersed in mud also showed cooking coconut oil biopolymer-rubber composite with 2% w/v PHBV to attract less mud than 3% w/v PHBV. In line with tensile test results, the 2P12-L8-CC1 yielded one of the lowest weight after immersing in mud, and therefore, was selected as the suitable material for footwear shells.

- *Material composition for corrective insoles:* a suitable material for corrective insole should pose high degree of crystallinity and high compressive strength in order to support wearer's weight and force during gait. Results showed cooking coconut oil biopolymer-rubber composite with 3% w/v PHBV to consistently generate higher degree of crystallinity, as compared with 2% w/v PHBV. Conform to degree of crystallinity, the compositions of P6-L4-CC1 and P5-L5-CC1 yielded less deformation when composed of 3% w/v of PHBV, as compared with 2% w/v of PHBV blends. With the 3P6-L4-CC1 was slightly superior in terms of both degree of crystallinity and compressive strength, the 3P6-L4-CC1 was selected as the suitable material for corrective insoles.

4.4. Study 4: Results of muscle activity when walking on rigid and muddy ground

According to computation results, the knee and ankle was found to be exposed to the greatest force increase due to mud resistance (see Figure 11). EMG results showed muddy ground to induce significantly higher levels of BiF and GA (knee and ankle) muscle exertion, as compared with rigid ground. Participants utilized higher activity levels of a certain set of BiF and GA muscles to compensate for mud viscous force. Substantially higher GA activity might result from a higher propulsion force from plantar flexion required for backward gait initiation. Such high GA activity requirements also complement the result of foot pain perception induced by excessive force. Prolonged repetition of GA exertion might lead to muscle fatigue and increase of risk of structural malalignment of the feet (Nguyen and Shultz, 2009), which correlates well with the high prevalence of abnormal alignment found in foot condition. The resulting high force required from knees and ankles of rice farmers is expected to be attenuated by our proposed AT in the next phases.

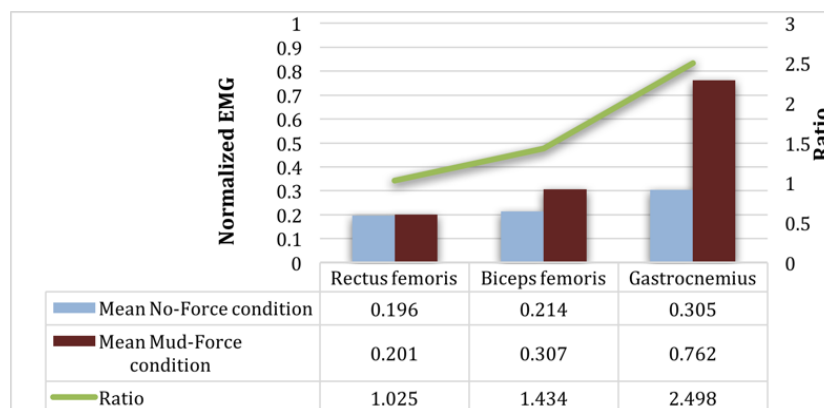


Figure 11. Muscle activity for muddy (Mud-Force condition) and rigid (No-Force condition) surface

4.5. Study 5: Results of AT design and prototype

A process of design and prototype proposed AT was divided into 2 parts as follows:

- *Footwear shells*: the shell parts of footwear were cut and sized according to the patterns. The material sheets were then assembled by heat press to form a boot-like shape footwear.
- *Corrective insoles*: To design corrective insole parts, we integrated the use of 3-dimensional optical scan of individual foot, a clinical examination by physical therapists, computer-aided (CAD) modeling and rapid prototyping processes. The corrective wedge was designed to correct individual rearfoot angle, forefoot varus, and filling in of the arch. The first prototype was developed as a 3D printed polymer insert with P/L/C composites padded. Figure 12 illustrates an example of polymer insert design and a P/L/C composites pad.

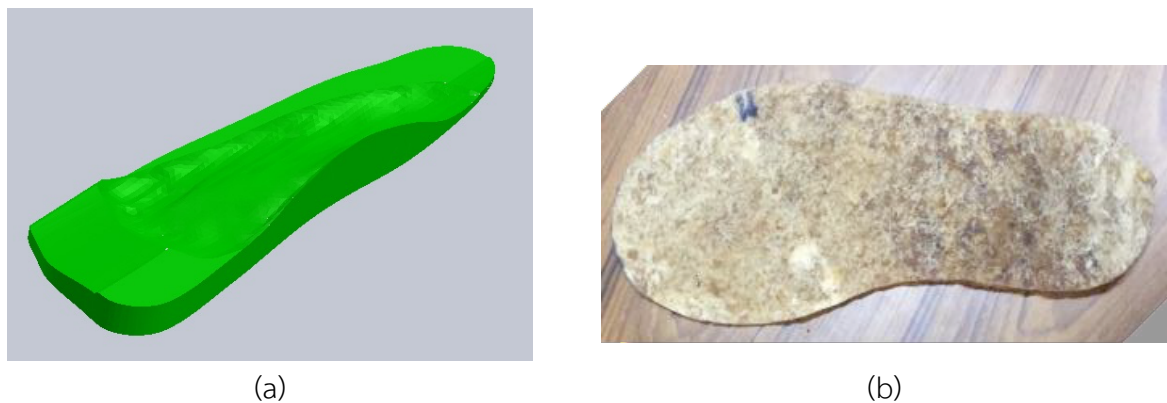


Figure 12. Example of corrective insole components: (a) polymer insert and; (b) PHBV-Latex - Cooking coconut oil composites pad

4.6. Study 6: Results of investigation of effects of proposed AT

The experiment was conducted to investigate effects of proposed AT, as compared with barefoot and common footwear, in terms of muscle use during standing and lifting foot from the mud. The descriptive results (Table 5) showed the proposed AT footwear to induce the lowest levels of tibialis anterior (TA) muscle exertion while standing on the mud. While standing in muddy terrain, participants adopted excessive foot pronation due to compensation for ankle and foot instability and control of body alignment. Such condition required TA muscle activity decelerate foot pronation. It is evident that corrective insoles incorporated in the proposed AT footwear helped reduce degree of foot eversion, and therefore alleviated requirements of TA activity.

During lifting the feet off the muddy ground, results showed that the proposed AT footwear required the lowest levels of GA muscle exertion and lower levels of BiF muscle, as compared with wearing common boots. The selected material of AT footwear attenuated force requirement from participants to compensate for mud viscous force, especially for propulsion force from plantar flexion (GA activity). Although BiF muscle activity generated when wearing the AT footwear was higher than when participants were walking barefoot, the higher muscle activity might be due to additional weight of footwear. When comparing with heavy common boots, the lightweight AT footwear still required less BiF to flex the knees out of mud. Since footwear is important personal protective equipment (PPE) to protect slip and cut injury for rice farmer while working in the field, the AT footwear proposed in this research provided a potential intervention for use as PPE for rice farmers. The proposed AT footwear would also help reducing and preventing risk from overexertion of muscles and potential of abnormal alignments of farmers' LE in their occupational tasks.

Table 5. Muscle activity (mean (SD) during standing and foot lifting from muddy terrain for varied footwear conditions

Conditions	Standing phase	Foot lifting phase	
	Tibialis Anterior (TA)	Biceps Femoris (BiF)	Gastrocnemius (GA)
Barefoot	9.58 (0.46)	21.50 (3.36)	28.19 (1.68)
Common footwear	9.44 (0.14)	24.82 (0.97)	21.57 (1.15)
AT footwear	8.35 (0.33)	23.58 (0.98)	19.23 (0.47)

5. สรุป

This research attempted to map the musculoskeletal and disability conditions of non-occupational disabled population (CP patients) and work-related disabilities of the LE of rice farmers. Results revealed the prevalence of LE malalignments of CP patients to be highest in foot pronation and knee valgus. Such malalignments were in line with results of previous farmer investigation. Related to this, results of surveys of musculoskeletal pain and examination of origin of pain showed similar characteristics between the two populations. Therefore, these associations could be used as a basis for extending AT designs for patients in daily living activities to farmers in work tasks.

A work-related risk factor of muddy work surface was also investigated in order to examine effects of such work terrain to muscle activity requirement. Results showed muddy

ground to induce significantly higher levels of BiF and GA muscle exertion, as compared with rigid ground. Therefore, such working terrain as well as knee and foot exertion were focused when developing AT for farmers.

Another main objective of this research was to develop AT design for rice farmers based on orthotic devices of CP patients. Based on literature reviews, current orthotic technologies of flexible footwear and corrective insoles were identified as possible interventions to farmers in rice cultivation work. Biopolymer and natural rubber were indicated as potential materials for AT design for farmers. Mechanical and chemical property tests were conducted for varied ratios of P/L/C composite. The test results illustrated that the biopolymer to rubber ratio of 3:2 was suitable for AT footwear shells and corrective insoles application in muddy terrain. The AT footwear equipped with corrective insoles was subsequently designed and prototyped using foot scanning technology and rapid prototyping to provide individual correction of foot deformation.

A small-scale experimental study was conducted with participants with foot pronation using custom design AT footwear for each individual. A planting task was simulated to compare knee and foot muscle activities when working with: barefoot, wearing common boots and wearing AT footwear. The results showed the proposed AT footwear to induce the lowest levels of TA, used to impede foot eversion, while standing on the mud. The AT footwear also required the lowest GA exertion and lower BiF activity, as compared with wearing common boots, during lifting the feet off the muddy terrain.

This research provided a potential intervention for reducing and preventing risk of LE injury for rice farmers. However, a limited numbers of rice farmers, who exhibits foot pronation condition, was investigated in the study. Follow-on research is expected to include more numbers of farmers, both with and without foot pronation conditions, in order to collectively correct and prevent risk of LE injury. Furthermore, the future research will also include improvement of AT design in terms of design of aesthetics, design of manufacturing and assembly, and dual-population usage.

6. Output จากโครงการวิจัยที่ได้รับทุนจาก สกว.

6.1. ผลงานตีพิมพ์ในวารสารวิชาการนานาชาติ

6.1.1. *Journal articles*

1. Juntaracena, K., **Neubert, M. S.** & Puntumetakul, R. (2018). Effects of muddy terrain on lower extremity muscle activity and discomfort during the rice planting process. *International Journal of Industrial Ergonomics*. 66, 187-193.

2. Kristanto, A., **Neubert, M. S.**, Promkottra, S., & Sessomboon, W. (2019). Fabrication and thermo-mechanical characteristics of PHBV/latex/vegetable oil composites-modifying on biocomposites. *Journal of Mechanical Engineering Research and Developments*. 42(5), 124-127.

3. Kristanto, A., **Neubert, M. S.**, Puntumetakul, R., & Sessomboon, W. (*in review*). Adaptable ergonomics interventions for patients with cerebral palsy to rice farmers activities: reviews and recommendations. *Submitted to Asia-Pacific Journal of Science and Technology*.

6.1.2. *Refereed conference proceedings*

1. **Neubert, M. S.**, Puntumetakul, R., & Karukunchit, U. (2018). Work postural and environmental factors for lower extremity pain and malalignment in rice farmers. The 20th Congress International Ergonomics Association (IEA2018). Florence, Italy (August 26-30).

6.2. การนำผลงานวิจัยไปใช้ประโยชน์

6.2.1. *เชิงสาธารณะ (มีเครือข่ายความร่วมมือ)*

This research is a multidisciplinary study involving team members with human factors (Dr. Neubert, PI) and materials science (Assoc. Prof. Dr. Sarunya Promkottra, Geotechnology, KKU) and physical therapy (Assoc. Prof. Dr. Rungthip Puntumetakul, Mentor, KKU; Dr. Usa Karukunchit, Physical Therapy, Saint Louis College) backgrounds.

The project is also for an international collaborative research with the U.S. partners in industrial engineering at University of Florida (Prof. Dr. David Kaber, formerly worked at North Carolina State University (NCSU)) and physical therapists at the University of North Carolina at Chapel Hill (UNC-CH) (Prof. Dr. Michael Gross).

6.2.2. *เชิงวิชาการ (มีการพัฒนาการเรียนการสอน/สร้างนักวิจัยใหม่)*

พัฒนาและสร้างนักศึกษาระดับปริญญาเอก 1 คน และนักศึกษาระดับปริญญาโท 1 คน ได้แก่

- Mr. Agung Kristanto, KKU Doctor of Engineering, Industrial Engineering (In progress) (Chair). (อาจารย์จาก Department of Industrial Engineering, Faculty of

Industrial Technology, Universitas Ahmad Dahlan ประเทศอินโดนีเซีย ได้มาศึกษา
งานวิจัยต่อยอดในระดับปริญญาเอก เนื่องจากมีความสนใจจากการไปนำเสนอผลงานวิจัย
ก่อนหน้านี้ที่ได้รับทุนสนับสนุนจาก สกว. รหัสสัญญาเลขที่ MRG5680009)

- Mr. Komkrit Juntaracena, KKU Master of Engineering, Industrial Engineering
(Graduated) (Chair).

6.3. ผลงานอื่นๆ

6.3.1. Conference presentation

1. **Neubert, M. S.**, Puntumetakul, R., Gross, M. T. & Kaber, D. B. (2019). Investigation of work-related risk factors and comparison with musculoskeletal conditions from congenital disability: rationale and design for assistive technology aiding agricultural workers. *Oral presentation at The 18th TRF-OHEC Annual Congress*. Phetchaburi, Thailand (January 9-11).

6.3.2. Invited presentation

1. **Neubert, M. S.** (June 28, 2018). Research from Thailand: Paddy Field. Work Health and Safety: Research to Practice Workshop, KKU, Khon Kaen, Thailand.

2. **Neubert, M. S.** (April 1, 2019). Case-study: Research in Occupational Health and Safety Technology. Seminar presentation to faculty and graduate students of School of Public Health, Khon Kaen University, Khon Kaen, Thailand.

6.3.3. Exhibition

1. งานเปิดศูนย์การเรียนรู้อุตสาหกรรมเกษตร TE Outlet, Faculty of Technology, Khon Kaen University. จัดแสดงนิทรรศการผลงานวิจัยและนวัตกรรมเกี่ยวกับอุตสาหกรรมเกษตรในงานเปิดศูนย์การเรียนรู้อุตสาหกรรมเกษตร TE Outlet วันที่ 27 สิงหาคม 2562 โดยแสดงผลงานวิจัยใน theme “Rapid Prototyping for Agricultural Application” ซึ่งมีผู้เข้าร่วมงานได้แก่ ที่ปรึกษารักษาการแทนอธิการบดีมหาวิทยาลัยขอนแก่น ประธานสภาอุตสาหกรรมจังหวัดขอนแก่น ผู้เข้าร่วมงานจากสภาอุตสาหกรรมหอการค้าจังหวัดขอนแก่น ผู้บริหารมหาวิทยาลัย ประธานสมาคมศิษย์เก่า พร้อมผู้สนใจจากทั้งภาครัฐและเอกชนอีกจำนวนมาก

7. References

- Abou-Zeid, D.M. (2001). Anaerobic biodegradation of natural and synthetic polyesters. Ph.D. Dissertations in Science, Technical University Carolo-Wilhelmina at Brunswick, Germany.
- Alagesan J, Shetty A. (2011). Effect of modified suit therapy in spastic diplegic cerebral palsy-a single blinded randomized controlled trial. *Online J Health Allied Sci*; 9: 14.
- Alam, M., Choudhury, I.A., Bin Mamat, A., & Hussain, S. (2015). Computer Aided Design and Fabrication of a Custom Articulated Ankle Foot Orthosis. *J. Mech. Med. Biol.* 15, 1550058.
- Autti-Ramo, I., Suoranta, J., Anttila, H., Malmivaara, A., & Makela, M. (2006). Effectiveness of upper and lower limb casting and orthoses in children with cerebral palsy - An overview of review articles. *Am. J. Phys. Med. Rehabil.* 85, 89–103.
- Bailes AF, Greve K, Burch CK, et al. (2011). The effect of suit wear during an intensive therapy programme in children with cerebral palsy. *Pediatr Phys Ther*; 23: 136–42.
- Bar-Haim, S., Harries, N., Belokopytov, M., Frank, A., Copeliovitch, L., Kaplanski, J., & Lahat, E. (2006). Comparison of efficacy of Adeli suit and neurodevelopmental treatments in children with cerebral palsy. *Dev. Med. Child Neurol.* 48, 325–330.
- Barwick, A., Smith, J., & Chuter, V. (2012). The relationship between foot motion and lumbopelvic hip function: a review of the literature. *The Foot* 12, 224-231.
- Blackley, D. C. (1997). *Polymer Latexes: Science and Technology : Types of latexes* (2nd ed., Vol. 2). Springer.
- Blackmore, A.M., Boettcher-Hunt, E., Jordan, M., & Chan, M.D.Y. (2007). A systematic review of the effects of casting on equinus in children with cerebral palsy: an evidence report of the AACPD. *Dev. Med. Child Neurol.* 49, 781–790.
- Boldingh, E. J., Jacobs-van der Bruggen, M. A., Lankhorst, G. J., & Bouter, L. M. (2004). Assessing pain in patients with severe cerebral palsy: Development, reliability, and validity of a pain assessment instrument for cerebral palsy. *Archives of physical medicine and rehabilitation*, 85(5), 758-766.
- Branthwaite, H. R., Payton, C. J., & Chockalingam, N. (2004). The effect of simple insoles on three-dimensional foot motion during normal walking. *Clinical Biomechanics*, 19, 972–977.
- Brouwer, R. W., van Raaij, T. M., Jakma, T. T., Verhagen, A. P., Verhaar, J. A., & Bierma-Zeinstra, S. (2005). Braces and orthoses for treating osteoarthritis of the knee. *The Cochrane Library*.
- Byl, N.N. (2012). Mobility training using a bionic knee orthosis in patients in a post-stroke chronic state: a case series. *J. Med. Case Reports* 6, 216.
- Chapman, C. (1999). Chairside orthoses—the end of casting? *Podiatry Now*, 4.
- Chen, M. J., Chen, C. P., Lew, H. L., Hsieh, W. C., Yang, W. P., & Tang, S. F. (2003). Measurement of forefoot varus angle by laser technology in people with flexible flatfoot. *American journal of physical medicine & rehabilitation*, 82(11), 842-846.

- Chen, J.-C., Dennerlein, J.T., Shih, T.-S., Chen, C.-J., Cheng, Y., Chang, W.P., Ryan, L.M., & Christiani, D.C. (2004). Knee Pain and Driving Duration: A Secondary Analysis of the Taxi Drivers' Health Study. *Am. J. Public Health* 94, 575–581.
- Chuter, V. H., & Janse de Jonge, X. (2012) Proximal and distal contributions to lower extremity injury: a review of the literature. *Gait and Posture* 36, 7-15.
- Corry, I.S., Cosgrove, A., Duffy, C., S, M., TC, T., & HK, G. (1995). Botulinum toxin A as an alternative to serial casting in the conservative management of equinus in cerebral palsy. *Dev. Med. Child Neurol.* 37, 20–21.
- Corry, I.S., Cosgrove, A.P., Duffy, C.M., McNeill, S., Taylor, T.C., & Graham, H.K. (1998). Botulinum Toxin A Compared with Stretching Casts in the Treatment of Spastic Equinus: A Randomised Prospective Trial. *J. Pediatr. Orthop.* 18, 304.
- Costa, C.R., McElroy, M.J., Johnson, A.J., Lamm, B.M., & Mont, M.A. (2012). Use of a static progressive stretch orthosis to treat post-traumatic ankle stiffness. *BMC Res. Notes* 5, 348.
- Cottalorda, J., Gautheron, V., Metton, G., Charmet, E., & Chavrier, Y. (2000). Toe-walking in children younger than six years with cerebral palsy. The contribution of serial corrective casts. *J. Bone Joint Surg. Br.* 82, 541–544.
- Cullell, A., Moreno, J. C., Rocon, E., Forner-Cordero, A., & Pons, J. L. (2009). Biologically based design of an actuator system for a knee–ankle–foot orthosis. *Mechanism and Machine Theory*, 44(4), 860-872.
- Flett, P.J., Stern, L.M., Waddy, H., Connell, T.M., Seeger, J.D., & Gibson, S.K. (1999). Botulinum toxin A versus fixed cast stretching for dynamic calf tightness in cerebral palsy. *J. Paediatr. Child Health* 35, 71–77.
- Font-Llagunes, J.M., Pàmies-Vilà, R., Alonso, J., Cuadrado, J. (2012). Dynamic analysis of walking with a powered stance-control knee-ankle-foot orthosis. *J. Biomech.* 45, S514.
- Frank AJ, Moll JM, & Hort JF. A comparison of three ways of measuring pain. *Rheumatol Rehabil* 1982;21:211-7.
- Glanzman, A.M., Kim, H., Swaminathan, K., Beck, T. (2004). Efficacy of botulinum toxin A, serial casting, and combined treatment for spastic equinus: a retrospective analysis. *Dev. Med. Child Neurol.* 46, 807–811.
- Ho, C. C. (1989). Changes in electrokinetic properties of natural rubber latex after surface chemical modifications. *Colloid and Polymer Science*, 267(7), 643–647.
- Ho, C. C., Kondo, T., Muramatsu, N., & Ohshima, H. (1996). Surface Structure of Natural Rubber Latex Particles from Electrophoretic Mobility Data. *Journal of Colloid and Interface Science*, 178(2), 442–445.

- Hsu, L., Huang, G., Lu, C., Chen, Y., Yu, I., & Shih, H. (2007). The integration of cad API environment and RP technology for supporting the design and manufacturing of transtibial prosthetic socket. *J. Biomech.* 40, S476.
- Jovanović, V., Samaržija-Jovanović, S., Budinski-Simendić, J., Marković, G., & Marinović-Cincović, M. (2013). Composites based on carbon black reinforced NBR/EPDM rubber blends. *Composites Part B: Engineering*, 45(1), 333-340.
- Jovanović, S., Samaržija-Jovanovic, S., Markovic, G., Jovanovic, V., Adamovic, T., & Marinovic-Cincovic, M. (2018). Ternary NR/BR/SBR rubber blend nanocomposites. *J. Thermoplast. Compos. Mater.* 31, 265–287.
- Juntaracena, K., & Swangnetr, M. (2016). Effects of Muddy Work Terrain on Force of Rice Farmer Lower Extremity Joints during Rice Planting Process. Presented at the the 4th IIAE International Conference on Industrial Application Engineering, Japan.
- Kaewkannetra, P., & Promkotra, S. (2013). Quality Improvement and Characteristics of Polyhydroxyalkanoates (PHAs) and Natural Latex Rubber Blends. *Defect Diffus. Forum* 334–335, 49–54.
- Khamis, S., & Yizhar, Z. (2007). Effect of feet hyperpronation on pelvic alignment in a standing position. *Gait & Posture* 25, 127-134.
- Knox, V. (2003). The Use of Lycra Garments in Children with Cerebral Palsy: A Report of a Descriptive Clinical Trial. *Br. J. Occup. Ther.* 66, 71–77.
- Kundu, P.P. (2000). Improvement of Filler-rubber Interaction by the Coupling Action of Vegetable Oil in Carbon Black Reinforced Rubber. *J. appl. Polym. Sci.*, 75, 735–739.
- Kuntanoo, K., Promkotra, S., & Kaewkannetra, P. (2013). Biodegradation of Polyhydroxybutyrate-Co-Hydroxyvalerate (PHBV) Blended with Natural Rubber in Soil Environment. *World Acad. Sci. Eng. Technol.* 7, 1799–1803.
- Kuntanoo, K., Promkotra, S., & Kaewkannetra, P. (2015a). Fabrication of Novel Polyhydroxybutyrate-co-Hydroxyvalerate (PHBV) Mixed with Natural Rubber Latex. *Key Eng. Mater.* 659, 404–408.
- Kuntanoo, K., Promkotra, S., & Kaewkannetra, P. (2015b). Physical-Biopolymer Characterization of Polyhydroxybutyrate-Co-Hydroxyvalerate (phbv) Blended with Natural Rubber Latex. *AIP Conf. Proc.* 1653.
- Landorf, K. B., & Keenen, A. M. (1999). Efficacy of foot orthoses: What does the literature tell us? *Podiatry Now*, 2(10), 331–336.
- Le, H. H., Pham, T., Henning, S., Klehm, J., Wießner, S., Stöckelhuber, K. W., ... & Vennemann, N. (2015). Formation and stability of carbon nanotube network in natural rubber: Effect of non-rubber components. *Polymer*, 73, 111-121.

- Mavroidis, C., Ranky, R.G., Sivak, M.L., Patritti, B.L., DiPisa, J., Caddle, A., Gilhooly, K., Govoni, L., Sivak, S., Lancia, M., et al. (2011). Patient specific ankle-foot orthoses using rapid prototyping. *J. Neuroengineering Rehabil.* 8, 1.
- McCourt, F.C. (1990). To cast or not to cast? The comparative effectiveness of casted and non casted orthoses. *The Chiropodist* 45, 239–243.
- Meyer-Heim, A., van Hedel, H.J.A. (2013). Robot-Assisted and Computer-Enhanced Therapies for Children with Cerebral Palsy: Current State and Clinical Implementation. *Semin. Pediatr. Neurol.*, Update on Cerebral Palsy: Diagnostics, Therapies and the Ethics of it All 20, 139–145.
- Nandan, V., Joseph, R., & Kuriakose, A.P. (1997). in *Proceedings of the National Conference, Indian Rubber Institute, Mumbai*, pp. 205–221.
- Nguyen, A. D., & Shultz, S. J. (2009). Identifying relationships among lower extremity alignment characteristics. *Journal of Athletic Training* 44, 511–518.
- Nicholson, J.H., Morton, R.E., Attfield, S., & Rennie, D. (2001). Assessment of upper-limb function and movement in children with cerebral palsy wearing lycra garments. *Dev. Med. Child Neurol.* 43, 384–391.
- Novak, I., McIntyre, S., Morgan, C., Campbell, L., Dark, L., Morton, N., Stumbles, E., Wilson, S-A. & Goldsmith, S. (2013). A systematic review of interventions for children with cerebral palsy: state of the evidence. *Developmental Medicine & Child Neurology*, 55(10), 885-910.
- Promkotra, S., & Kangsadan, T. (2015). Tensile Strength of PHBV/Natural Rubber Latex Mixtures. *MATEC Web Conf.* 35, 01001.
- Rennie, D.J., Attfield, S.F., Morton, R.E., Polak, F.J., & Nicholson, J. (2000). An evaluation of lycra garments in the lower limb using 3-D gait analysis and functional assessment (PEDI). *Gait Posture* 12, 1–6.
- Rethlefsen, S., Kay, R., Dennis, S., Forstein, M., & Tolo, V. (1999). The Effects of Fixed and Articulated Ankle-Foot Orthoses on Gait Patterns in Subjects with Cerebral Palsy. *J. Pediatr. Orthop.* 19, 470.
- Richards, J. D., Sanchez-Ballester, J., Jones, R. K., Darke, N., & Livingstone, B. N. (2005). A comparison of knee braces during walking for the treatment of osteoarthritis of the medial compartment of the knee. *Bone & Joint Journal*, 87(7), 937-939.
- Richtler, H. J., & Knaut, J. (1983). *Challenges to a Mature Industry*. Henkel KGaA, Dusseldorf.
- Sae-oui, P., Sirisinha, C., & Hatthapanit, K. (2007). Effect of blend ratio on aging, oil and ozone resistance of silica-filled chloroprene rubber/natural rubber (CR/NR) blends. *Express Polym. Lett.* 1, 8–14.
- Stell, J., & Buckley, J. (1998). Controlling excessive pronation: A comparison of casted and non-casted orthoses. *The Foot*, 8(4), 179–240.
- Telfer, S., & Woodburn, J. (2010). The use of 3D surface scanning for the measurement and assessment of the human foot. *J. Foot Ankle Res.* 3, 19

- Thomas, S.S., Buckon, C.E., Jakobson-Huston, S., Aiona, M.D., & Sussman, M.D. (2000). Sagittal plane kinematics of the hip, knee and ankle in children with hemiplegia during stair ascent and descent utilizing three different ankle foot orthosis (AFO) configurations. *Gait Posture* 11, 158.
- Watt, J., Sims, D., Harckham, F., Schmidt, L., McMillan, A., & Hamilton, J. (1986). A prospective study of inhibitive casting as an adjunct to physiotherapy for cerebral-palsied children. *Dev. Med. Child Neurol.* 28, 480–488.
- Weisman J., & Broscole L. (1994). Facial affect recognition in singly diagnosed mentally retarded people and normal young children: a methodological comparison. *Int J Neurosci* ;75:45-55.
- Weng, Y.-X., Wang, Y., Wang, X.-L., & Wang, Y.-Z. (2010). Biodegradation behavior of PHBV films in a pilot-scale composting condition. *Polym. Test.* 29, 579–587.
- Witinuntakit, T., Kiatkamjornwong, S., & Poompradub, S. (2018). Dichlorocarbene modified butadiene rubber (DCBR): Preparation, kinetic study, and its properties in natural rubber/DCBR blend vulcanizates. *Polym. Adv. Technol.* 29, 649–657.
- Yakimovich, T., Lemaire, E. D., & Kofman, J. (2009). Engineering design review of stance control knee-ankle-foot orthoses. *Journal of rehabilitation research and development*, 46(2), 257.

Appendix



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 farmers 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/m². 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

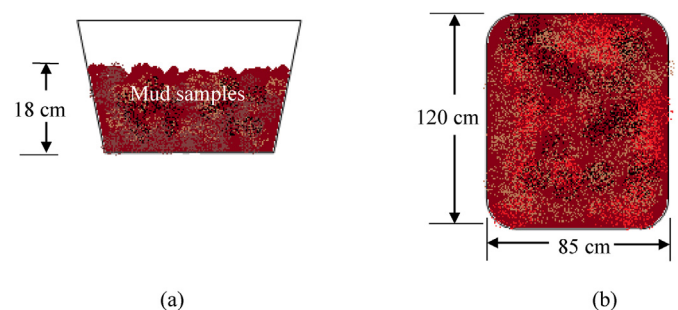


Fig. 1. Mud samples contained in a tray shown in: (a) side view and; (b) top view.

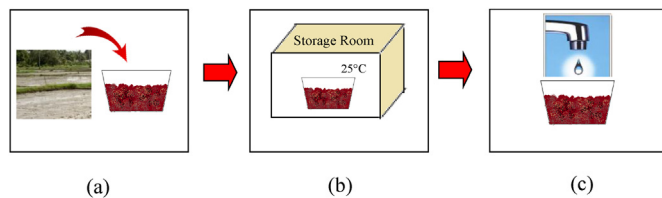


Fig. 2. Experimental mud sample preparation procedure: (a) collect mud samples from the actual planting site; (b) store samples in the controlled temperature room; (c) fill samples with water.

in the mud (13 cm) retrieved from previous measurements conducted directly in the field (Juntaracena and Swangnetr, 2016), and extended by an additional 5 cm to compensate for any possible variations beyond the average immersion depth. The samples were subsequently refilled and soaked with different amounts of water for another 3 days (see preparation procedure in Fig. 2). Applied water volumes of 42, 46, 50 and 53 L, corresponding to approximate ratios of water content to mud of 23%, 25%, 27% and 29%, respectively, were adopted from literature examples (Zhang et al., 2016). The test results showed that the experimental mud sample with 50 L of water exhibited the most similar viscosity characteristics to the “fresh” mud sample. Therefore, the preparation procedure applying 50-L water content was selected for subsequent experimental trials.

2.3. Task and experimental conditions

In addition to the percentage of water in the mixture, mud viscous force also depends on speed, external force and time of exposure (Schramm, 2006). Although the influence of external force from individual weight could not be eliminated, this study endeavored to control other factors, including hand load, work posture and movement pace. The details of task and experimental conditions are as follows:

The participants were asked to perform the simulated rice planting task at 2 conditions (see Fig. 3): 1) No-Force condition (performing task on rigid surface) and; 2) Mud-Force condition (performing task on muddy surface). In both experimental conditions, participants were asked to carry a bundle of wood sticks, simulating rice sprouts with a typical weight force of 3 kg, in the left hand and 0.3 kg (weight force of one tenth of a bundle) in the right hand. A high angle side view of all motions was recorded with a video camera during the entire planting performance simulation. The order of experimental conditions was assigned randomly at the beginning of the experiment. Once the participants were assigned to a specific order of condition, they were asked to complete a total of 10 sessions of the first condition before continuing to perform a set of 10 sessions of the second condition. The number of 10 sessions was estimated along with the number of participants to achieve a sufficient statistical power (significance level of 0.95 and desired power of 0.8) for supporting all EMG analyses (Diggle, 2002).

Participants were instructed to perform the simulated planting task

by using their right hands to push a small bundle of sprouts into the ground. Each session included the performance of 3 planting activities per row by moving the upper body in half-circular motion from the left to the right side, for a total of 3 rows per session (see Fig. 3 for illustration). The participants were then instructed to take a backward step of approximately 35–40 cm by lifting and placing their right feet before starting the subsequent planting row. A metronome set to 60 beats/minute (similar to the usual planting pace) was used to control the pace of upper body movement and step in planting activities. Participants initially practiced the movement tempo and step length before beginning the experiment to avoid re-dos or mistakes. In addition, the metronome aided in standardizing speed and time of exposure factors across individuals. During the experimental performance, EMG signals of muscles of the right LE side were collected throughout the test trials. At the end of each condition, participants were asked to rate their discomfort perception for each part of the LE resulting from task performance on the corresponding condition. The break between the two conditions was set to be 5 min to avoid potential muscle fatigue (Rullmann and Kleisinger, 2003).

2.4. Response measures

2.4.1. Muscle activity

EMG electrodes were placed over the right side of the subject's LE muscles, including rectus femoris (RF; part of the quadriceps group), biceps femoris (BF; part of the hamstring group) and gastrocnemius (GA). The muscle selection was based on LE joint angles during gait initiation in specific rice planting tasks affected by mud viscous force. For the swing leg (i.e., the first leg to leave the ground), hip and knee need to be flexed (Mann et al., 1979; Elble et al., 1994), resulting in activity of RF and BF, respectively. In a typical forward gait, the ankle starts with dorsiflexion to move the body forwards over the feet (Mann et al., 1979; Elble et al., 1994). However, for backward gait as examined in this study, backward propulsion is accomplished by ankle plantar flexors, which resulted mainly in activity of GA to create a reversed torque (Thorstensson, 1986; van Deursen et al., 1998). Although the tibialis anterior muscle may also contract eccentrically during backward gait initiation, this study did not investigate this muscle due to not being a prime contributor to reversed propulsion.

Three pairs of adhesive disposable Ag/AgCl disc surface electrodes (EL503, BIOPAC Systems, California) were placed over the anatomical locations of each muscle (see Fig. 4) based on the guidelines from previous research (Gazendam and Hof, 2007; Gallagher et al., 2011). The skin at the site of electrode placement was prepared by shaving, abrading and cleaning with alcohol to reduce skin impedance to less than 10 kΩ (Hermens et al., 2000). An MP100 data acquisition system (Biopac Systems, Inc.) was used to continuously record EMG signals at 1000 Hz during the test trial. The signals were post-processed using 20–500 Hz bandpass and 50 Hz notch filters for eliminating electrical system interference. The full-wave rectified EMG signals were

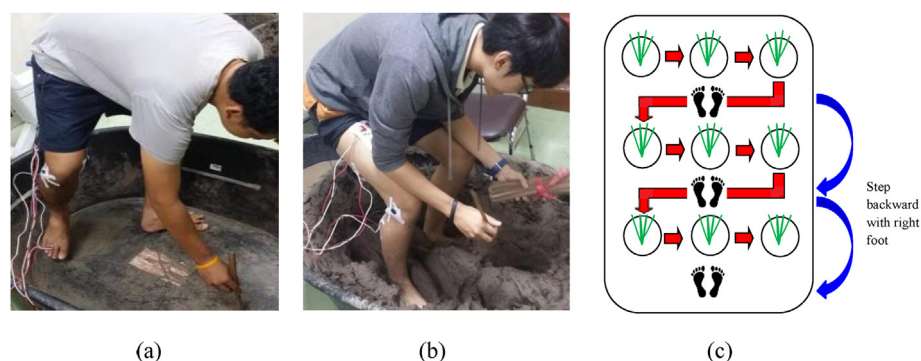


Fig. 3. Simulated planting task performance: (a) No-Force condition; (b) Mud-Force condition; (c) direction of movement.

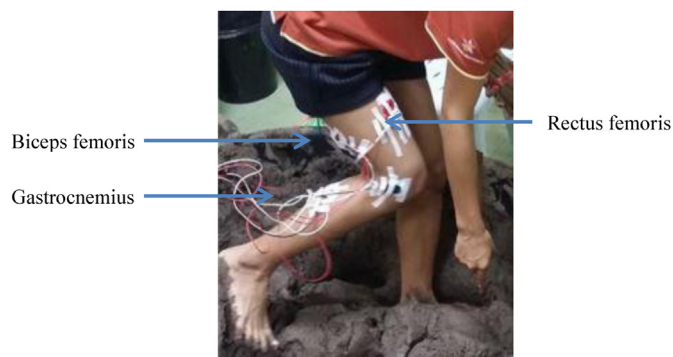


Fig. 4. EMG electrode locations of rectus femoris (RF), biceps femoris (BF) and gastrocnemius (GA) muscles.

normalized relative to the isometric maximal voluntary contraction (MVC) for the same muscle. The MVCs were captured in advance of the test trials by asking the participants to perform static maximum contractions for 3–5 s from a seated position (Konrad, 2005). To generate MVC for RF and BF, participants were asked to perform knee extension and knee flexion, respectively, with ankles strapped with a belt. To generate MVC for GA, participants were asked to perform a unilateral plantar flexion with a rigid fixation applied vertically at knees. Maximal contraction for each muscle was repeated 2 times and a 2-min rest period was provided for each contraction. The maximum EMG amplitude measured from the two MVC trials was taken as the reference value for normalizing test trial data. Mean values of normalized EMG of a selected interval were used for subsequent muscle activity analysis. According to the selected gait phases, the analysis interval included a range of EMG signals when subjects started lifting their right feet off the floor or mud until the highest point of lifting was reached.

2.4.2. Discomfort perception

The perceived discomfort questionnaire (Thai version) was used to collect self-report data of discomfort for each joint of the LE. The questionnaire was based on a body part diagram presented in the Standardized Nordic Questionnaire (SNQ; Kuorinka et al., 1987). Discomfort intensity was rated on 10-cm visual analog scales (VAS), which is sensitive to treatment effects (von Korff et al., 2000). The scales range from 0 to 10 points, where 0 represents no discomfort and 10 denotes intolerable discomfort. The questions included discomfort of separate sides of each LE parts (i.e., left and right sides of hip, knee and ankle/foot) participants experienced during the experimental process. Fig. 5 illustrates an excerpt of the questionnaire used in the present study, which has been shown to yield acceptable reliability in previous studies (e.g., Swangnetr et al., 2014; Udom et al., 2016).

2.5. Hypotheses

Based on the literature review, we expected an increase of LE muscle activity when participants perform work in the muddy surface environment (Mud-Force condition), as compared with working on the rigid surface (No-Force condition) (Hypothesis 1). Additional force exertion resulting from mud viscosity might overload LE muscles and tendons (Messing et al., 2006) and, therefore, is expected to increase perception of LE discomfort (Davis and Kotowski, 2007; Naidoo et al., 2009; Reid et al., 2010) (Hypothesis 2). The LE part influenced by the greatest effects from muddy terrain would be exposed to a high risk of injury.

2.6. Statistical analyses

An EMG-based muscle activity analysis during simulated planting tasks typical for the rice cultivation process was conducted to identify

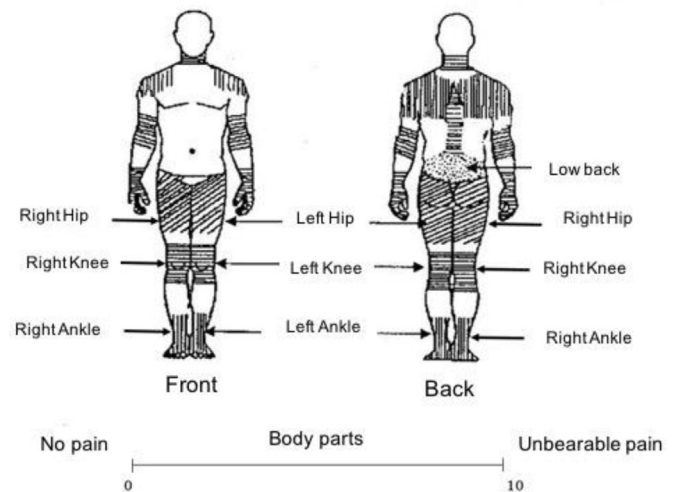


Fig. 5. Body part diagram and rating scale for perceived discomfort questionnaire.

potential effects of work surface conditions on LE muscles of rice farmers. The segment of LE muscle activity data corresponding to the lifting of the farmers' right feet away from the work surface was subjected to analysis. The normalized EMG response did not conform to the normality assumption; therefore, log transformation was applied to the response measurements. As participants were randomly assigned to one of the conditions and then repeated measurements were taken on each participant throughout the condition, repeated measure ANOVA was conducted to compare effects over time of No-Force and Mud-Force conditions on the (log-transformed) normalized muscle activity. The sessions were treated as within-subject factors in the repeated measure ANOVA models. Any significant changes in EMG response throughout the sessions indicated amplified or attenuated muscle activity required for performing the planting task in particular conditions over time. A discomfort perception analysis using paired *t*-test was conducted to compare subjective ratings of LE discomfort of subjects performing the planting task between No-Force and Mud-Force conditions. All analyses were performed using the SPSS version 19.0 software (IBM Corporation) based on a significance level of $\alpha = 0.05$. For some response measures, marginal significance was also reported based on an $\alpha = 0.10$.

3. Results

3.1. Results of muscle activity analysis

The repeated measure ANOVA results (see Fig. 6 and Table 1) show that the muscle activity did not significantly change during experimental sessions ($p > 0.05$). The interaction term of conditions and sessions also appeared insignificant. Based on this observation, no evidence for effects of the experimental conditions on changes of muscle activity over time could be found. BF and GA activities were significantly higher ($p < 0.05$) when participants performed tasks in the Mud-Force condition, as compared with the No-Force condition. Notably, the results presented in Fig. 6 illustrate the non-transformed values for better visualization. The observed ratio of GA muscle differences (2.5 times) was higher than the ratio of BF muscle differences (1.4 times).

3.2. Results of discomfort perception analysis

Paired *t*-test results (see Table 2) revealed the discomfort on the right (the first leg to lift) knee and ankle in the Mud-Force condition to

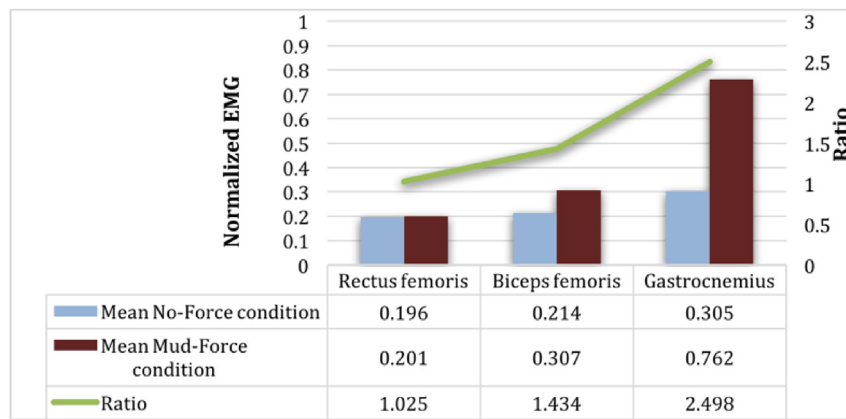


Fig. 6. Descriptive statistics of muscle activity for Mud-Force condition and No-Force condition.

Table 1

Results of repeated measure ANOVA of muscle activity comparison between Mud-Force condition and No-Force condition.

	Rectus femoris	Biceps femoris	Gastrocnemius
Condition	F(1,58) = 0.0002 p = 0.99	F(1,58) = 4.33 p = 0.04*	F(1,58) = 38.48 p < 0.0001*
Session	F(9,50) = 1.24 p = 0.29	F(9,50) = 1.28 p = 0.27	F(9,50) = 0.72 p = 0.69
Condition x Session	F(9,50) = 0.61 p = 0.79	F(9,50) = 1.10 p = 0.38	F(9,50) = 1.07 p = 0.40

Note: * indicates significant difference at $p < 0.05$.

Table 2

Results on comparison of LE pain perception between Mud-Force condition and No-Force condition using paired *t*-test.

		Left side			Right side (first lift)		
		Hip	Knee	Ankle	Hip	Knee	Ankle
Mean discomfort ratings (score)	No-Force	0.44	0.56	0.52	0.44	0.60	0.54
	Mud-Force	0.49	0.67	0.64	0.48	0.88	0.73
Statistical results	<i>t</i>	0.61	1.78	1.78	0.71	2.27	2.36
	<i>p</i>	0.54	0.09	0.08	0.48	0.03*	0.03*

Note: * indicates significant difference at $p < 0.05$.

be significantly higher than the perceived discomfort in the No-Force condition ($p < 0.05$). Discomfort in the left knee and ankle also appeared to be higher with marginal significance ($p < 0.1$) when performing tasks in Mud-Force condition. However, both sides of the hip were not perceived differently between No-Force and Mud-Force conditions.

4. Discussion

Partially in line with Hypothesis 1, BF and GA muscle activities were found to significantly increase when participants were working in the Mud-Force condition in comparison with the No-Force condition. Mud viscous force resulted in participants utilizing higher activity levels of a certain set of muscles (i.e., BF and GA) as for normal gait on rigid ground. An increase in BF and GA activity, which assisted knee flexion, was in line with results from a previous study conducted in our group (Juntaracena and Swangnetr, 2016), indicating the knee is exposed to the highest force increase due to mud viscous force. Substantially higher GA activity might result from a higher backward propulsion force from plantar flexion required for gait initiation. In addition, based on observations during the experimental trials, participants also

adjusted the leg geometry by flexing the ankle down to reduce the leg area immersed in the mud. This adaptation resembles the effects of straight leg geometry investigated by Ren et al. (2013) and Zhang et al. (2016), which were found to produce more propulsion efficiency compared to curve-shaped legs in muddy media. These findings are supplemented by a physical examination study of Karukunchit (2015), indicating the hamstring group and gastrocnemius muscles to be the first and third most affected structures by mud force, respectively, according to pain rating in rice farmers.

The analysis of discomfort perception was partially in line with Hypothesis 2. The collected results revealed that participants perceived significantly higher discomfort in the right knee and ankle during task performance on the Mud-Force surface, as compared with the No-Force surface. The significant discomfort perceived in the right knee and ankle by the participants also correlated with the more pronounced effects of muddy terrain on the BF and GA muscles. There was only marginal evidence of effects of muddy terrain on the perceived discomfort in the left knee and ankle (the second leg to leave the ground) ($p = 0.09$ and 0.08 , respectively). Although the participants were attached with EMG electrodes on the right legs only, the discomfort perception was presumably not caused by equipment-induced discomfort, as the perceived discomfort of left and right side within the same conditions was not statistically different ($p = 0.2$ – 0.8). A less pronounced discomfort in the left knee and foot might arise from the shift of the center of gravity towards the back of the body after lifting the right leg. Furthermore, participants were able to utilize the momentum generated by body weight and additional muscles to help pulling the left leg off the mud. Although our previous study (Juntaracena and Swangnetr, 2016) also illustrated an increase of force on hip joints due to working on a muddy surface, the absence of discomfort perception in the hip of participants observed in the present study might be due to the fact that pain associated with muscles is more pronounced during active movement, as compared with joint pain (Diaz, 2013). In this study, the GA muscle activation induced by task performance on muddy terrain displayed the highest increase (approximately 2.5 times) compared to the activation during rigid ground condition. Since GA is associated with knee flexion and ankle plantar flexion, participants might feel more noticeable discomfort in these parts. Initially, participants might only notice muscle pain in the first leg leaving the mud, but over time (and since this study was designed to cover only a short duration of task performance) perception of pain associated with joints and the other side of the leg may increase due to mud viscous force.

Related to this, prolonged walking was found to be a risk factor for hip, knee and ankle and foot injury (Naidoo et al., 2009; Davis and Kotowski, 2007; Reid et al., 2010; Osborne et al., 2012; Xiao et al., 2013). Additional force exertion resulting from mud viscosity during walking might overload certain lower extremity muscles and tendons

(Messing et al., 2006), thus leading to an increased risk of foot and knee injury and discomfort (Davis and Kotowski, 2007; Naidoo et al., 2009; Reid et al., 2010). These findings can be used as an additional guideline for lower limb self-care and may benefit the development of personal protective equipment or assistive devices with focus on knees and feet, which bears a great potential to drastically minimize the risk of LE injury during planting tasks.

Although the experimental mud samples were attentively prepared and designed to emulate the most commonly encountered real working situations, the fact that the mud layer height used in the experiment may still not cover the whole range of possible mud environments in a real rice field represents a limitation of the current study. As a result, the greater depth of the mud layer in a real rice field may provide better support of body weight than determined experimentally in this work. A future study should therefore employ an extended mud layer in order to better reflect the actual work conditions in a real rice field environment. Regarding experimental conditions, the current study did not control the immersion depth of individual participants' legs due to weight; and therefore, this might result in different contact area and resistance force levels. The simulated mud field was also not repositioned after each session, which might lead to inconsistency of mud resistance force. A future investigation should attempt to control such conditions to ensure consistent mud force throughout the experiment. Furthermore, this study included the investigation of muscle activity limited to one side of the LE and focused on a specific movement pattern, initiated by lifting the leg off the muddy surface before starting to move backward. As a result of this specific movement, the muscle activity level of the left leg might be different from the first-lifted (right) leg. Compared to other forms of movement, forward walking might involve more ankle dorsiflexion instead of plantar flexion activity. Other phases of gait, for example the stance phase, might require different sets of muscles to stabilize LEs immersed in soft terrain and to control body alignment (Donatelli and Wooden, 2009). In addition, extended periods of experimental trials might provide more insightful results of LE discomfort experienced during task performance on muddy terrain.

5. Conclusion

The collected results of this study revealed muddy work terrain to pose substantial risks to LE parts, specifically knee and foot. These findings provide additional evidence for the high prevalence of LE MSDs in farmers reported in previous studies (e.g., Puntumetakul et al., 2011; Osborne et al., 2012; Xiao et al., 2013). Exposure to planting activities involving repetitive movements and awkward knee bending postures, combined with heavy loads are unambiguously associated with knee pain due to the excessive loading on the knee joint and ultimately lead to fatigue and pain (Jones et al., 2007; Allen et al., 2010; D'Souza et al., 2008; Baker et al., 2003). The present study revealed the performance of certain tasks of the rice planting process in muddy ground to induce significantly higher levels of BF and GA (knee and ankle) muscle exertion due to mud viscosity, as compared with performance on rigid ground without mud (conformed to Hypothesis 1). This finding is supported by the greater perceived discomfort in knee and ankle areas in response to task performance on a muddy surface, as expected in Hypothesis 2. Prolonged repetition of such force exertion might overload LE muscles and increase risk of foot and knee injury (Davis and Kotowski, 2007; Naidoo et al., 2009; Reid et al., 2010; Messing et al., 2006). The results of this work correlated with a previous study focused on work-related injury for Thai rice farmers (Karukunchit et al., 2014b), in which expert ergonomist assessment revealed that during planting activity, LE parts are exposed to a high risk of injury due to excessive force. Structural malalignments of the knee and foot were also found to have a high prevalence among Thai rice farmers (Karukunchit et al., 2014a). Due to the significant detrimental effects from working on muddy terrain, emphasis should be put

on developing self-care programs, personal protective equipment and/or assistive devices to prevent LE injury to the knees and feet of farmers during rice cultivation task performance. Examples of possible interventions include the implementation of exercises that focus on strengthening hamstring group and gastrocnemius muscles, as well as the development of footwear coated with materials that reduce the resistive force upon extricating the feet from the mud. Future research will extend the investigation to forward walking conditions and other locomotion phases with the ultimate goal to develop assistive technology for the knees and feet of farmers to prevent or, at least, attenuate the ergonomic risks of the rice cultivation process.

Conflicts of interest

The authors have no personal or financial conflicts of interest associated with this work.

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References

- Allen, K.D., Chen, J.C., Callahan, L.F., Golightly, Y.M., Helmick, C.G., Renner, J.B., Jordan, J.M., 2010. Associations of occupational tasks with knee and hip osteoarthritis: the Johnston County osteoarthritis project. *J. Rheumatol.* 37 (4), 842–850.
- Baker, P., Reading, I., Cooper, C., Coggon, D., 2003. Knee disorders in the general population and their relation to occupation. *Occup. Environ. Med.* 60 (10), 794–797.
- Barbe, M.F., Barr, A.E., 2006. Inflammation and the pathophysiology of work-related musculoskeletal disorders. *Brain Behav. Immun.* 20 (5), 423–429.
- Bartlett, R., 2002. *Sports Biomechanics: Reducing Injury and Improving Performance*. Routledge.
- D'Souza, J.C., Werner, R.A., Keyserling, W.M., Gillespie, B., Rabourn, R., Ulin, S., Franzblau, A., 2008. Analysis of the Third National Health and Nutrition Examination Survey (NHANES III) using expert ratings of job categories. *Am. J. Ind. Med.* 51 (1), 37–46.
- Davis, K.G., Kotowski, S.E., 2007. Understanding the ergonomic risk for musculoskeletal disorders in the United States agricultural sector. *Am. J. Ind. Med.* 50 (7), 501–511.
- Diaz, L.G., 2013. *Survey of Athletic Injuries for Exercise Science*. Jones & Bartlett Publishers.
- Diggle, P., 2002. *Analysis of Longitudinal Data*. Oxford University Press.
- Donatelli, R.A., Wooden, M.J., 2009. *Orthopaedic Physical Therapy*. Elsevier health sciences.
- Elble, R.J., Moody, C., Leffler, K., Sinha, R., 1994. The initiation of normal walking. *Mov. Disord.* 9 (2), 139–146.
- Fathallah, F.A., 2010. Musculoskeletal disorders in labor-intensive agriculture. *Appl. Ergon.* 41 (6), 738–743.
- Fathallah, F.A., Miller, B.J., Miles, J.A., 2008. Low back disorders in agriculture and the role of stooped work: scope, potential interventions, and research needs. *J. Agric. Saf. Health* 14 (2), 221–245.
- Gallagher, S., Pollard, J., Porter, W.L., 2011. Electromyography of the thigh muscles during lifting tasks in kneeling and squatting postures. *Ergonomics* 54 (1), 91–102.
- Gazendam, Marnix G.J., Hof, L., 2007. Averaged EMG profiles in jogging and running at different speeds. *Gait Posture* 25, 604–614.
- Hermens, H.J., Freriks, B., Disselhorst-Klug, C., Rau, G., 2000. Development of recommendations for SEMG sensors and sensor placement procedures. *J. Electromyogr. Kinesiol.* 10 (5), 361–374.
- Jones, G.T., Harkness, E.F., Nahit, E.S., McBeth, J., Silman, A.J., Macfarlane, G.J., 2007. Predicting the onset of knee pain: results from a 2-year prospective study of new workers. *Ann. Rheum. Dis.* 66 (3), 400–406.
- Juntaracena, K., Swangnetr, M., 2016. Effects of muddy work terrain on force of rice farmer lower extremity joints during rice planting process. In: *Proceedings of the 4th IIAE International Conference on Industrial Application Engineering 2016*. Beppu, Japan (March 26–30).
- Karukunchit, U., 2015. *Physical Ergonomics Risk Factor Analyses of Lower Extremity Impairments in Rice Cultivation*. Dissertation. Khon Kaen University, Khon Kaen, Thailand.
- Karukunchit, U., Swangnetr, M., Puntumetakul, R., Eungpinichpong, W., Emasithi, A., 2014a. Prevalence of lower extremity malalignment in rice farmers. In: *The 5th International Conference on Applied Human Factors and Ergonomics*. Krakow, Poland.

- Karukunchit, U., Swangnetr, M., Puntumetakul, R., Juntaracena, K., Keawduangdee, K., 2014b. Ergonomic analysis for risk of lower extremity injury in rice cultivation process. In: The 6th International Conference on Public Health Among the Great Mekong Sub-regional Countries. Khon Kaen, Thailand.
- Karukunchit, U., Puntumetakul, R., Swangnetr, M., Boucaut, R., 2015. Prevalence and risk factors analysis of lower extremity abnormal alignment characteristics among rice farmers. *J. Pat. Pref. Adher.* 9, 785–795.
- Kirkhorn, S.R., Earle-Richardson, G., Banks, R.J., 2010. Ergonomic risks and musculoskeletal disorders in production agriculture: recommendations for effective research to practice. *J. Agromed.* 15 (3), 281–299.
- Konrad, P., 2005. The ABC of EMG. A Practical Introduction to Kinesiological Electromyography. (Scottsdale, AZ: Noraxon).
- Kuorinka, I., Jonsson, B., Kilbom, A., Vinterberg, H., Biering-Sørensen, F., Andersson, G., Jørgensen, K., 1987. Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms. *Appl. Ergon.* 18 (3), 233–237.
- Li, C., Zhang, T., Goldman, D.I., 2013. A terradynamics of legged locomotion on granular media. *Science* 339 (6126), 1408–1412.
- Mann, R.A., Hagy, J.L., White, V., Liddell, D., 1979. The initiation of gait. *J. Bone Joint Surg. Am.* 61 (2), 232–239.
- Marras, W.S., Cutlip, R.G., Burt, S.E., Waters, T.R., 2009. National occupational research agenda (NORA) future directions in occupational musculoskeletal disorder health research. *Appl. Ergon.* 40 (1), 15–22.
- Messing, K., Tissot, F., Stock, S.R., 2006. Lower limb pain, standing, sitting and walking: the importance of freedom to adjust one's posture. In: Proceedings of the 16th Congress of the International Ergonomics Association, Maastricht, Netherlands. Elsevier, Amsterdam, The Netherlands.
- Meyers, J.M., Miles, J.A., Faucett, J., Janowitz, I., Tejeda, D.G., Kabashima, J.N., 1997. Ergonomics in agriculture: workplace priority setting in the nursery industry. *Am. Ind. Hyg. Assoc. J.* 58 (2), 121–126.
- Ministry of Commerce of Thailand, 2017. Thailand Trading Report (Agricultural Products). Retrieved from. http://www.ops3.moc.go.th/infor/Export/recode_export_rank/report.asp.
- Mokkamul, P., 2006. Ethnobotanical study of rice growing process in Northeastern, Thailand. *Ethnobot. Res. Appl.* 4, 213–222.
- Naidoo, S., Kromhout, H., London, L., Naidoo, R.N., Burdorf, A., 2009. Musculoskeletal pain in women working in small-scale agriculture in South Africa. *Am. J. Ind. Med.* 52 (3), 202–209.
- Osborne, A., Blake, C., Fullen, B.M., Meredith, D., Phelan, J., McNamara, J., Cunningham, C., 2012. Risk factors for musculoskeletal disorders among farm owners and farm workers: a systematic review. *Am. J. Ind. Med.* 55 (4), 376–389.
- Puntumetakul, R., Siritaratiwat, W., Boonprakob, Y., Eungpinichpong, W., Puntumetakul, M., 2011. Prevalence of musculoskeletal disorders in farmers: case study in Sila, Muang Khon Kaen, Khon Kaen province. *J. Med. Technol. Phys. Ther.* 23 (3), 297–303.
- Ramirez, M., Schaffer, K.B., Shen, H., Kashani, S., Kraus, J.F., 2006. Injuries to high school football athletes in California. *Am. J. Sports Med.* 34 (7), 1147–1158.
- Reid, C.R., Bush, P.M., Karwowski, W., Durrani, S.K., 2010. Occupational postural activity and lower extremity discomfort: a review. *Int. J. Ind. Ergon.* 40 (3), 247–256.
- Ren, X., Liang, X., Kong, Z., Xu, M., Xu, R., Zhang, S., 2013. An experimental study on the locomotion performance of elliptic-curve leg in muddy terrain. In: 2013 IEEE/ASME International Conference on Advanced Intelligent Mechatronics. IEEE, pp. 518–523.
- Rullmann, M., Kleisinger, S., 2003. Ergonomic Investigations in the Prone Working Posture during Pickling Cucumber Harvesting. XXX CIOSTA CIGR V Management and technology applications to empower agriculture and agrofood systems, pp. 22–24.
- Schramm, L.L., 2006. Emulsions, Foams, and Suspensions: Fundamentals and Applications. John Wiley & Sons.
- Swangnetr, M., Kaber, D.B., Puntumetakul, R., Gross, M.T., 2014. Ergonomics-related risk identification and pain analysis for farmers involved in rice field preparation. *Work* 49 (1), 63–71.
- Thorstensson, A., 1986. How is the normal locomotor program modified to produce backward walking? *Exp. Brain Res.* 61 (3), 664–668.
- Tropea, C., Yarin, A.L., Foss, J.F., 2007. Springer Handbook of Experimental Fluid Mechanics, vol. 1 Springer Science & Business Media.
- Udom, C., Janwantanakul, P., Kanlayanaphotporn, R., 2016. The prevalence of low back pain and its associated factors in Thai rubber farmers. *J. Occup. Health* 58 (6), 534–542.
- van Deursen, R.W., Flynn, T.W., McCrory, J.L., Morag, E., 1998. Does a single control mechanism exist for both forward and backward walking? *Gait Posture* 7 (3), 214–224.
- von Korf, M., Jensen, M.P., Karoly, P., 2000. Assessing global pain severity by self-report in clinical and health services research. *Spine* 25 (24), 3140–3151.
- Xiao, H., McCurdy, S.A., Stoecklin-Marais, M.T., Li, C.S., Schenker, M.B., 2013. Agricultural work and chronic musculoskeletal pain among Latino farm workers: the MICASA study. *Am. J. Ind. Med.* 56 (2), 216–225.
- Zhang, S., Zhou, Y., Xu, M., Liang, X., Liu, J., Yang, J., 2016. AmphiHex-I: locomotory performance in amphibious environments with specially designed transformable flipper legs. *IEEE ASME Trans. Mechatron.* 21 (3), 1720–1731.

RESEARCH ARTICLE

FABRICATION AND THERMO-MECHANICAL CHARACTERISTICS OF PHBV/LATEX/VEGETABLE OIL COMPOSITES-MODIFYING ON BIOCOMPOSITES

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ABSTRACT

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Polyhydroxybutyrate-co-hydroxyvalerate (PHBV, P) and natural latex (L) are mixed together to improve biostructures due to very stiff PHBV and high resilient natural latex. Another raw material added in PHBV/L mixtures is a vegetable oil which is vary between virgin coconut oil (VC) and cooking coconut oil (CC). Then, the three mixtures are known for P-L-C biocomposites. These three different components among PHBV, natural latex, and the coconut oil are considered to obtain their proper mechanical properties. The 2% and 3% (w/v) of PHBV concentrations (2P, 3P) in chloroform are started as the main component, and mixed to natural latex (L) and coconut oil (VC or CC) as the blended films in the ratio of 12:8:1, 10:10:1, 8:12:1, and compared to 6:4:1, 5:5:1, 4:6:1, respectively. The blends are specified the thermal property by the differential scanning calorimetry and also distinguished with their crystallinity. Besides, they are also characterized the tensile strength by universal testing machine. The degree of crystallinity is inversely proportional to the melting temperature particularly for 3Px-Lx-C1. The 3% w/v of PHBV-Latex-Coconut oil blends presents higher melting temperature than the 2% w/v of PHBV-Latex-Coconut oil mixtures. Adding coconut oil mixes show a lower melting temperature at 166-167°C when is compared to the mixture without coconut oil at 168-169°C. The virgin coconut oil mixes specify no inconsistency of the melting temperature, enthalpy, and degree of crystallinity. The addition of the coconut oil can diminish the 50% of tensile strength and the 6-7% of tensile modulus. The cooking coconut oil added in the 2% w/v PHBV-Latex matrix affects a 10% increase in tensile modulus related to the 3% w/v PHBV-Latex matrix. The appearance of the coconut oil in the blend is suitable for conformity of plastic deformation.

KEYWORDS

Mechanical characteristics, Tensile strength, Latex, PHBV, Coconut Oil, Biocomposite.

1. INTRODUCTION

Bio-based complexes are extremely experimented in recent years due to their certain properties and obviously explicit environmental influence. Polyhydroxyalkanoates (PHAs) are one of biodegradable polymers on aliphatic polyesters, produced organically from microbial activity on sugar-based medium. A type of polyhydroxybutyrate-co-hydroxyvalerate (PHBV) is a distinctive instance of PHAs, with decent biodegradability fabricating by many microorganisms [1]. Crystalline configurations of PHBV chains and co- monomer contributions are statistically arbitrary forms. The HV contents of 3HB (hydroxybutyrate) and 3HV (hydroxyvalerate) copolymers provide their property changes. The major concerning properties of PHBV biopolymers are basically rigid, brittle and low resilient materials which are unapproachability of outstanding mechanical property [2]. To improve their mechanical properties, various revision has been suggested and processed of PHBV and mixed with natural rubber latex, for example the chemical variation and physical mingling. The mechanical examinations indicate complex specific configurations of mechanical properties of the PHBV/Latex blends which higher PHBV content signifies the better elastic modulus [3]. The outcomes of mechanical and thermal properties express that the blended PHBV are capable to develop their properties by more elasticity and broad range of temperature. Moreover, the biodegradable PHBV is mixed with a green tea polyphenol (TP) as toughened. Mechanical and thermal properties of composites show that PHBV/TP matrix is able to improve the toughness of the composites [4]. The results of the differential scanning calorimetric (DSC) present a single glass transition and an inferior melting temperature. Several matters based on PHBV are improved

their properties by blending to other biodegradable polymers, such as natural rubber, epoxide natural rubber [5], polybutylene adipate-co-terephthalate [6].

Natural latex rubber is a material that has gained much scientific attention due to the present extensive utilization of non-renewable supplies and the naturally toxic discarding required for conventional polymers. Property of natural rubber presents a soft and high elastic material. Some nanoparticles are used as filler to improve strength and ultimate deformation. The mainly important of rubber is the enhanced reinforcement by stiff objects, such as dispersed additives or phase-separated organic parts [7]. Compatibility of the rubber blended to other components contributes extra interrelated phases, which can develop the properties. Block copolymers are useful for congruent phase-segregated combinations, by diminishing the surface tension [8] and instantaneously increasing the strength of the interfacial sections [9-10]. Concentrated researches related to filler types is to develop the mechanical properties of elastomeric materials as natural rubber, such as carbon nanotubes, carbon black, and some clays [11-12]. Another substance for blending in natural rubber is vegetable oils. They have plenty of free fatty acids which are useful for mixing in rubber compounds. Some vegetable oils act as a vulcanizing agent in carboxylate nitrile rubber blends [13]. To develop their mechanical properties and processability, linseed oil is beneficial additive in rubber compound. Soybean oil is exploited as a plasticizer in natural rubber [14]. Also, castor oil is acted as a plasticizer in nitrocellulose and rubbers containing styrene. Basically, vegetable oils behave as a coupling agent for development of rubber-filler interaction in carbon black [15].

One of vegetable oils is coconut oil which contains high saturated fat content or fatty acid, known as medium chain triglycerides, such as lauric acid, capric acid, caprylic acid, and caproic acid. However, this coconut oil is still contained a small amount of long chain triglycerides. To improve physical properties of PHBV and natural latex blends, coconut oil is selected to be an additive in a natural latex composition containing the oil-extended latex rubber as a component. The purpose of this research is to provide a coconut oil as a plasticizer- increased latex containing PHBV component. The PHBV concentration is controlled in two series of 2% and 3% w/v in chloroform blending with fresh creamy latex. The coconut oil is compared to both virgin coconut oil and cooking coconut oil. This biopolymer product is intended to reveal the mechanical characteristics of the blends related on its thermal property, focusing the attention on vegetable oil in terms of thermo-mechanical properties.

2. MATERIALS AND METHODS

Powder PHBV (trade name ENMAT Y1000), commercial grade, is provided from Ningbo Tianan Biologic Material Co. Ltd., China. It dissolves in chloroform (A.R. grade) at 2% and 3% w/v around 4 hr and controls temperature at 65-70°C. This PHBV solution (P) is ready to mix with other two components, creamy latex and coconut oil. The natural latex (L) is supplied by Rubber Authority of Thailand (Khon Kaen Branch) where is cultivated from the rubber tree (*hevea brasiliensis*) in the northeast of Thailand. The last component is coconut oil, commercial grade, and acquired from a local market. Two different types of coconut oil (C) are produced in Thailand and varied in this experiment as a plasticizer. They are virgin coconut oil (VC) and cooking coconut oil (CC). The total fat and saturated fat in the virgin coconut oil are 18% and 55%, respectively. However, the total fat in the cooking coconut oil is 18%, and no saturated fat in the portion.

The PHBV solutions in different concentration of 2% and 3% w/v (2P, 3P) are first agitated with coconut oil at room temperature. Subsequently, these mixtures of PHBV and coconut oil are vigorous blended with the natural latex (L) in three different portions and controlled the temperature at 50°C during mixing. Only the three different ratios of PHBV-Latex-Coconut oil, compared to the two series of 12:8:1, 10:10:1, 8:12:1, and 6:4:1, 5:5:1, 4:6:1, are produced and examined for thermo-mechanical test (Table 1). After energetic blending, shaping biopolymeric film with extruder allows a dried sheet at 50°C for 3 days in the oven. Thermal characteristics of these biopolymer products are examined by the differential scanning calorimetry (DSC), NETZSCH DSC 214 Polyma, Germany, based on ASTM E794 - 06 (Standard Test Method for Melting and Crystallization Temperatures by Thermal Analysis). The DSC results

reveal certain aspects of melting temperature (T_m), enthalpy (ΔH), and crystallinity (%).

Mechanical test is performed by using Universal Testing Machine (UTM, Instron 5567A). Specimen size measuring refers to ASTM D882-10 with a rectangular shape of specimens, dimension specifications as 100 mm in total length, 20 mm width, and 50 mm in gauge length (benchmark). Thickness of the specimen is closely to 1.0 mm which is measured by a vernier caliper. Three specimens of each composite film are tested for calculating the average of a set of tensile data. Before the test, the specimens are hold tightly with pneumatic grips and controlled a crosshead speed of 5 mm/min.

3. RESULTS AND DISCUSSION

The PHBV has been mixed with natural latex and vegetable oil that affords reinforcing appearance for the intention of formulating value-added outcomes. The challenge to discover proper blend affiliates for PHBV is to develop PHBV properties. The formulation of the blends is presented in Table 1. Three components with several concentrations and the mixing ratios are varied in two series, entirely compared their physical properties together.

3.1 Differential Scanning Calorimetry (DSC):

The biopolymer films are examined for thermal and mechanical properties by the differential scanning calorimetry (DSC) which specifies a prompt method for verifying polymer crystallinity depended on the heat involved to their melts. This technique measures heat flow in/out of a biopolymer as a function of temperature. Thermograms attained from the first heating scan for the PHBV-Latex biocomposites (P-L), and PHBV-Latex- Coconut oil (P-L-C) blends are shown in Figure 1. Melting temperature (T_m) and enthalpy are obtained from the first heating scan. However, the degree of crystallinity of blends is calculated by computing the heat associated with melting (fusion) of these composites. This heat is stated as crystallinity in percent by normalizing with respect to the fusion heat of a 100 % PHBV crystalline sample, as indicated in Equation (1).

$$\text{Degree of crystallinity} = (\Delta H_f - \Delta H_c) / \Delta H_{f, 100\%} \times 100\% \quad (1)$$

where ΔH_f is the enthalpy of melting, ΔH_c is the enthalpy of crystallization, and $\Delta H_{f, 100\%}$ is the enthalpy of melting for a fully PHBV crystalline polymer based upon 55.40 J/g.

Table 1: Thermal property of PHBV-Latex-Vegetable oil composite which vegetable oil is virgin coconut oil (VC) and cooking coconut oil (CC) (Remark: T_m is melting temperature.)

Item	PHBV-L-C (2% w/v)	T_m (°C)	Enthalpy (ΔH) (J/g)	Crystallinity (%)	PHBV-L-C (3% w/v)	T_m (°C)	Enthalpy (ΔH) (J/g)	Crystallinity (%)
1	2P3-L2	169.0	3.39	6.12	3P3-L2	168.9	6.81	12.29
2	2P1-L1	167.5	3.54	6.39	3P1-L1	167.6	4.74	8.56
3	2P2-L3	167.8	3.81	6.88	3P2-L3	167.8	6.05	10.92
4	2P12-L8-VC1	167.3	3.64	6.57	3P12-L8-VC1	167.5	5.76	10.40
5	2P10-L10-VC1	167.6	3.58	6.46	3P10-L10-VC1	167.6	5.23	9.44
6	2P8-L12-VC1	167.8	3.12	5.63	3P8-L12-VC1	167.6	3.90	7.04
7	2P6-L4-VC1	167.6	4.69	8.47	3P6-L4-VC1	166.9	4.15	7.49
8	2P5-L5-VC1	167.6	6.12	11.05	3P5-L5-VC1	165.9	4.46	8.05
9	2P4-L6-VC1	167.2	1.60	2.89	3P4-L6-VC1	166.4	3.35	6.05
10	2P12-L8-CC1	166.8	3.92	7.08	3P12-L8-CC1	167.0	6.08	10.97
11	2P10-L10-CC1	167.3	3.79	6.84	3P10-L10-CC1	167.2	5.65	10.20
12	2P8-L12-CC1	166.9	3.41	6.16	3P8-L12-CC1	166.4	5.42	9.78
13	2P6-L4-CC1	167.1	2.25	4.06	3P6-L4-CC1	166.5	5.58	10.07
14	2P5-L5-CC1	166.9	2.82	5.09	3P5-L5-CC1	166.0	5.40	9.75
15	2P4-L6-CC1	167.6	2.74	4.95	3P4-L6-CC1	166.3	3.77	6.81
16	PHBV	175.0	55.40					
17	Rubber	204.1	9.12					

The area under a main peak is the enthalpy. The results of crystallinities (%) for the blend products are summarized in Table 1. The comprehension of the degree of crystallinity is significant to reveal the affected physical properties, for instance melting temperature, elastic modulus, and density. Mostly these appearances of crystallinity provide a primary property to predict other physical properties. Overall degree of crystallinity for the 3% w/v of PHBV blends (3Px-Lx-Cx) presents higher than the 2% w/v of PHBV blends (2Px-Lx-Cx), except for the series of 2P6-L4-VC1 and 2P5-L5-VC1

(Figure 2). The coconut oil mixes show a lower melting temperature (166-167°C) compared to the mixture without coconut oil (xPx-Lx) (168-169°C). Moreover, the virgin coconut oil mixes indicate the physical properties of a poor inconsistency of T_m , enthalpy, and degree of crystallinity. Melting points of 3Px-Lx-C1, in which increase both virgin- and cooking coconut oil, obviously decrease in the range of 1.0-1.5°C, as indicated in Figure 3.

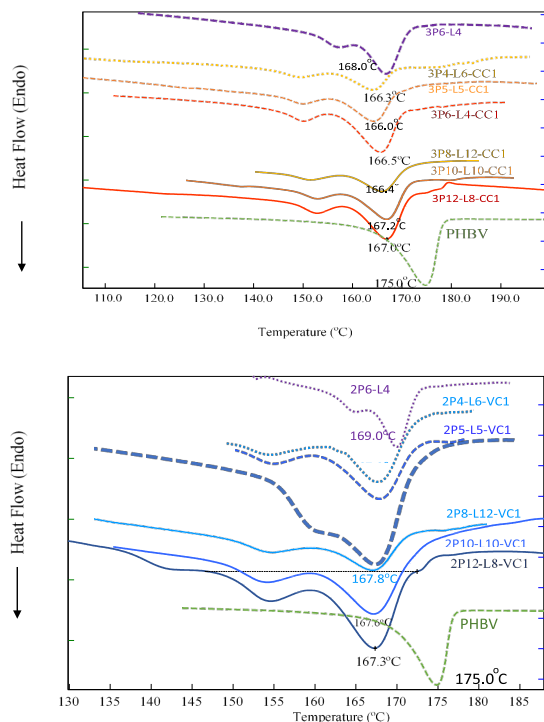


Figure 1: Melting endotherms for biopolymer films in different compositions of PHBV-Latex-Coconut oil (Px-Lx-Cx) by vary the concentrations of PHBV (2%, 3% w/v) and the ratio of PHBV, latex, and both virgin coconut oil (VC) and cooking coconut oil (CC), corresponding to Table 1

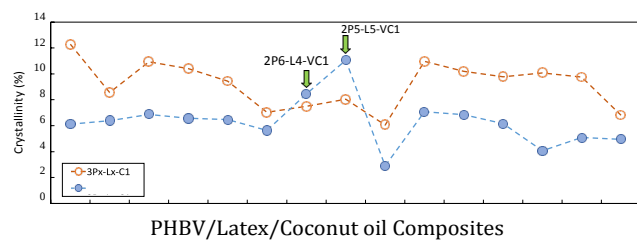


Figure 2: Crystallinity (%) related to the composite materials of PHBV-Latex-Coconut oil in different mixing ratio, corresponding to Table 1

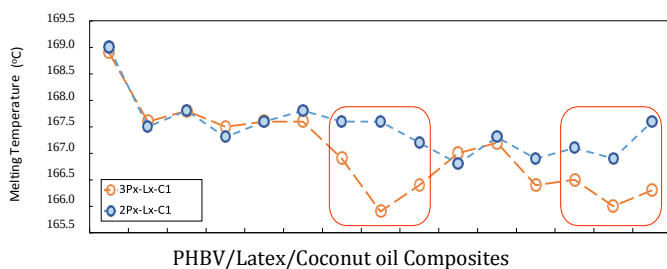


Figure 3: Melting temperature related to the composite materials of PHBV-Latex-Coconut oil in different mixing ratio, corresponding to Table 1

3.2 Tensile Testing

The tensile stress as a function of the tensile strain of the 2-3% w/v PHBV-Latex composite made without coconut oil, 2Px-Lx and 3Px-Lx, shows the ultimate strengths of 130-160 KPa and 60-120 KPa, as given in Figure 4, respectively. The addition of the virgin coconut oil and cooking coconut oil can decrease the tensile strength of PHBV by 50% (Figure 5) and the tensile modulus by 6-7% (Figure 6). The addition of the coconut oil to the 2% w/v PHBV-Latex matrix results in a 10% increase in tensile modulus compared to the 3% w/v PHBV-Latex matrix, especially for cooking coconut oil (CC) of 2P12-L8-CC1 (Figure 5b). However, there are very important variations in the tensile elastic modulus and yield strength for the 2% w/v PHBV-Latex-Virgin coconut oil (2Px-Lx-VC1). The reason is that the virgin coconut oil has an extra 55% saturated fat, but the cooking coconut oil has nil. According to Figure 2-3, the degree of crystallinity is increase in 3Px-Lx-C1, however, its melting temperature presents lower than 2Px-Lx-C1. The effect of low melting temperature obviously

influences to the reduction in modulus and yield strength of both 3Px-Lx-VC1 and 3Px-Lx-CC1 composites. The presents of the coconut oil in the blends are attributed to conformity declaration of plastic deformation after yield until break, particularly the cooking coconut oil. Without the coconut oil, this property is not dominated. Increase the amount of coconut oil twice to the PHBV-Latex matrix affects the short elongation at break of this composite and also quickly 50% failures.

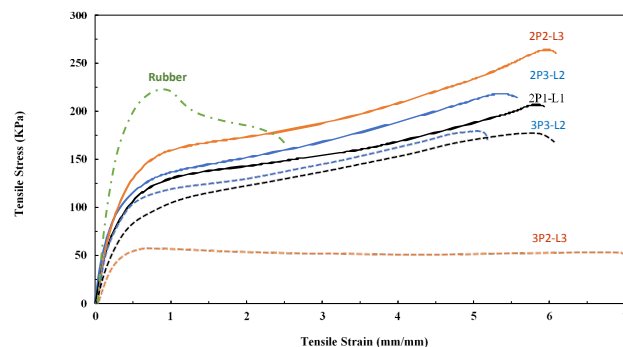


Figure 4: Tensile stress as a function of tensile strain of PHBV (P) and latex (L) in two PHBV concentrations (2% and 3% w/v of PHBV: 2P, 3P), with the blend composition ratio of 3:2, 1:1, and 2:3; for example, 2P2-L3 represents 2% (w/v) of PHBV with the addition of latex in the ratio of 2:3; compared to rubber

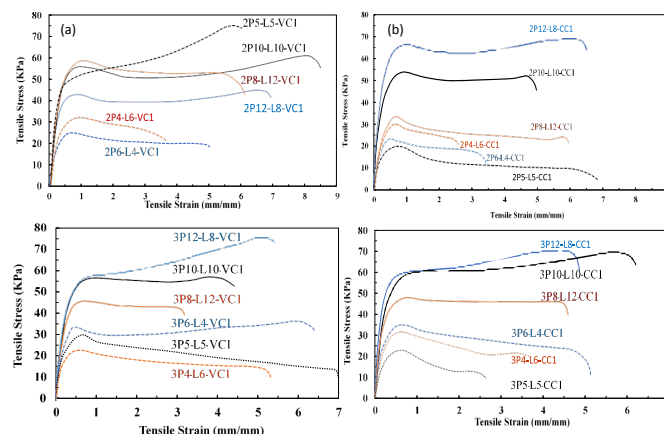


Figure 5: Tensile stress as a function of tensile strain of P/L samples in two PHBV concentrations (2% and 3% w/v of PHBV-2P, 3P) with the addition of virgin coconut oil (VC) and cooking coconut oil (CC) to the P/L components by two composition series in the ratio of (I) 12:8:1 10:10:1, 8:12:1, and (II) 6:4:1, 5:5:1, 4:6:1 (a) 2Px-Lx-VC1, (b) 2Px-Lx-CC1, (c) 3Px-Lx-VC1, and (d) 3Px-Lx-CC1

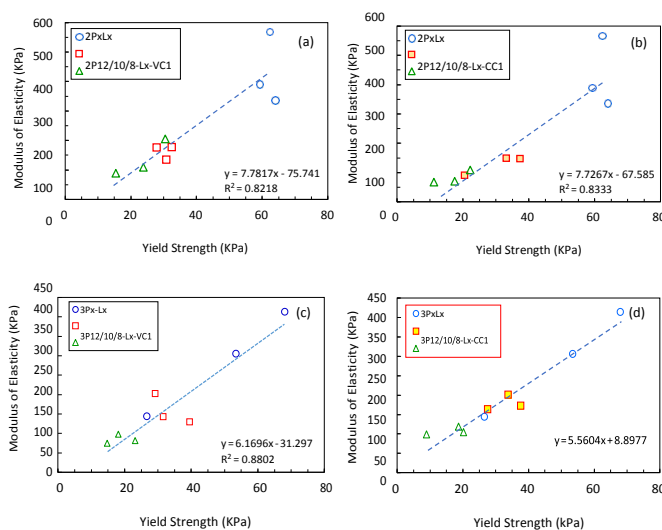


Figure 6: Modulus of elasticity related to yield strength of PHBV/Latex/Vegetable oil in two PHBV concentrations (2% and 3% w/v of PHBV-2P, 3P) with the addition of virgin coconut oil (VC) and cooking coconut oil (CC) to the P/L components which are compared to 3 groups of mix- and unmix vegetable coconut oils (a) 2% PHBV-Latex-Virgin coconut oil, (b) 2% PHBV-Latex-Cooking coconut oil, (c) 3% PHBV-Latex-Virgin coconut oil, and (d) 3% PHBV-Latex-Cooking coconut oil

4. CONCLUSIONS

The results acquired outstandingly that adding the coconut oil in PHBV and natural latex mixtures can develop the physical characterizations of the PHBV-Latex blends, specifically their thermal and mechanical properties. The degree of crystallinity is inversely proportional to the melting temperature for 3Px-Lx-C1 which is lower than 2Px-Lx-C1. The 3% w/v of PHBV-Latex-Coconut oil blends presents higher melting temperature than the 2% w/v of PHBV-Latex-Coconut oil mixtures.

Adding coconut oil mixes show a lower melting temperature (166-167°C) compared to the mixture without coconut oil (168-169°C). The virgin coconut oil mixes specify poor inconsistency of the melting temperature, enthalpy, and degree of crystallinity. Melting points of 3Px-Lx-C1 with the coconut oil obviously decrease melting temperature in the range of 1.0-1.5°C. No coconut oil (2Px-Lx and 3Px-Lx) shows the ultimate tensile strengths at 130-160 KPa and 60-120 KPa, respectively. The addition of the coconut oil can decrease the 50% of tensile strength and the 6-7% of tensile modulus. The cooking coconut oil added to the 2% w/v PHBV-Latex matrix causes a 10% increase in tensile modulus compared to the 3% w/v PHBV-Latex matrix. The presents of the coconut oil in the blends are qualified to correspondence of plastic deformation after yield.

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REFERENCES

[1] K. Kuntanoo, S. Promkottra, and P. Kaewkannetra. 2013. Biodegradation of polyhydroxybutyrate-Co- hydroxyvalerate (PHBV) blended with natural rubber in soil environment, *International Journal of Materials and Metallurgical Engineering*, vol. 7, no. 12, 1057-1061.

[2] P. Kaewkannetra and S. Promkottra. 2013. Quality improvement and characteristics of polyhydroxyalkanoates (PHAs) and natural latex rubber blends, *Defect and Diffusion Forum*, vol. 334-335, 49-54.

[3] K. Kuntanoo, S. Promkottra, and P. Kaewkannetra. 2015. Physical-biopolymer characterization of polyhydroxybutyrate-co-hydroxyvalerate (PHBV) blended with natural rubber latex, *AIP Conf. Proc.*, vol. 1653, 020063-1-020063-8.

[4] H. X. Xiang, S. H. Chen, Y. H. Cheng, Z. Zhou, and M. F. Zhu. 2013. Structural characteristics and enhanced mechanical and thermal properties of full biodegradable tea polyphenol/poly(3-hydroxybutyrate-co-3 hydroxyvalerate) composite films, *EXPRESS Polymer Letters*, vol. 7, no. 9, 778-786.

[5] F. Akram, C. H. Chan, and V. D. Natarajan. 2013. Investigation of miscibility of P(3hydroxybutyrate-co 3hydroxyhexanoate) and epoxide natural rubber blends, *AIP Conference Proceedings*, 1674, 0200311 0200316.

[6] S. Z. A. Zaidi and A. Crosky. 2017. High strength, high toughness polyhydroxybutyrate-co-valerate based Biocomposites, *International Journal of Materials and Metallurgical Engineering*, vol. 11, no. 1.

[7] G. R. Hamed. 2000. Reinforcement of Rubber, *Rubber Chemistry and Technology*, vol. 73, no. 3, 524-533.

[8] N. Virgilioa, P. Desjardinsb, G. L'Espérance, B.D. Favis. 2010. *Polymer*, vol. 51, 1472.

[9] J. A. Galloway, H. K. Jeon, J. R. Bell, C. W. Macosko. 2005. *Polymer*, vol. 46, 183.

[10] J. E. Puskas, G. Kaszas. 2001. *Rubber Chem. Technol.*, vol. 74, 583.

[11] V. Jovanovic, S. Samarzija-Jovanovic, J. Budinski-Simendic, G. Markovic, and M. Marinovic-Cincovic. 2013. Composites based on carbon black reinforced NBR/EPDM rubber blends, *Compos Part B*, vol. 45, 333-340.

[12] H. H. Le, T. Pham, S. Henning, J. Klehm, S. Wiefßner, S. Stöckelhuber, A. Das, X.T. Hoang, Q. K. Do, M. Wu, N. Vennemann, G. Heinrich, and G. Radusch. 2015. Formation and stability of carbon nanotube network in natural rubber: Effect of non-rubber components, *Polymer*, vol. 73, 111-121.

[13] H. J. Richtler. 1983. Challenges to a Mature Industry, *Dusseldorf: Henkel KGaA*.

[14] V. Nandanan, R. Joseph and A.P. Kuriakose. 1997. in *Proceedings of the National Conference, Indian Rubber Institute, Mumbai*, 205-221.

[15] P.P. Kundu. 2000. Improvement of Filler-rubber Interaction by the Coupling Action of Vegetable Oil in Carbon Black Reinforced Rubber *J. appl. Polym. Sci.*, vol. 75, no. 735-739.



Adaptable Ergonomic Interventions for Patients with Cerebral Palsy to Rice Farmers Activities: Reviews and Recommendations

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Abstract

People with cerebral palsy (CP) are functionally restricted to differing degrees due to a decrease of main control and coordination of movements. Although inherently different in causation, a previous study demonstrated that physical disabilities faced by CP patients might also be experienced by rice farmers due to the risky working environment and unsafe working posture. Research on assistive technology (AT) for CP population was extensively conducted, whereas AT studies for preventing farmer disadvantage were limited. Certain ATs developed for patients with CP might also be benefit to healthy rice farmers exposed to extreme working environments to prevent occupational injuries. This article provides a constrained review of available ergonomic interventions for patients with CP disability that bear prospect to be applicable to rice farmers. All papers were retrieved from the last 20-years collection from nine major search engines, including: “Scopus”, “Web of Science”, “CINAHL”, “Cochrane Database of Systematic Reviews”, “Education Source”, “ERIC”, “Journals@OVID”, “MEDLINE”, and “PASCAL”. Specified terms of “ergonomic interventions”, “congenital disability”, “cerebral palsy”, and “orthoses” were used as search keywords. Two independent reviewers defined whether the articles complied to the inclusion criteria of: (1) a review or the next best available; (2) contains ergonomic interventions; and (3) more than 25% of participants were persons with CP. So far, there were 21 articles relating to the research of ergonomic interventions for people with CP. The interventions studied in those articles were categorized as: (1) engineering, (2) administrative and, (3) behavioral interventions. Detailed discussions regarding to adaptability of each intervention were then provided in terms of capability for assistance, improvement and prevention of MSD problems. Most studies reported engineering and administrative interventions to significantly improve motor function and gait characteristics. Behavioral interventions successfully promoted positive mood and behavior, as well as reduced stress and oppositional behavior. Types of intervention for CP patients that might be adaptable for farmers were discussed, along with related examples that had been proposed for reducing risk of injury among paddy field farming workers. In general, the findings indicated most adapted interventions were based on educational programs, with no attempt to adapt engineering interventions from CPs for farmers. We recommended that a certain combination of engineering and administrative interventions for CPs treatment, with slight modifications, may be applicable to farmers for preventing risky environmental conditions and unsafe working postures.

Keywords: Ergonomic interventions, Congenital disability, Cerebral palsy, Paddy field farming

1. Introduction

Disability can be generally divided into two main groups based on the causation, namely congenital disabilities and circumstantial disabilities [1]. Congenitally disabled people with cerebral palsy (CP) display a walking-related disability or muscular weakness, which is often caused by upper neuron disorders [2]. Previous studies indicated that certain characteristics of the working environment can potentially render healthy workers to have performances comparable to that of disabled people. It was also noted that indirect disabilities induced by various work-related tasks may possibly lead to physical and cognitive conditions resembling congenital disabilities [1 & 3]. With this possible association, muscle injury encountered by CP patients might, also be developed by rice farmers due to the unsafe work posture and environmental conditions experienced while paddy field [4].

The most common tasks during rice cultivation in Asian countries are still performed in a traditional fashion, involving awkward work posture and harsh environmental conditions. Typical examples for such processes of paddy field farming include plowing, seeding, planting, nursing, fertilizing, and harvesting [5]. Notably, almost all stages of paddy farming involve repetitive motions, uncomfortable postures, heavy lifting and carrying, prolonged standing, and control of heavy and vibrating machinery [6]. Specifically, the plowing task is conducted by using a heavy vibrating plowing machine, while the seeding, nursing, and fertilizing activities implicate heavy lifting and carrying. The planting stage involves repetitive forward trunk bending and twisting and prolonged stooping and walking is required during harvest. All these tasks clearly represent risk factors for biomechanical malfunction and chronic musculoskeletal disorders (MSDs) [6], which is further emphasized by a previous study reporting the rate of occurrence for MSDs among Thai rice farmers ranging between 10.3-73.3% [7]. In addition, a high prevalence for foot pronation and knee valgus has been found with percentages of 20.9% and 18.5%, respectively [8]. This situation is exacerbated by the preference of farmers to perform their work with bare feet, since the muddy work environment in the paddy field has previously been found to increase force loading on foot and knee joints and muscles due to adverse effects of ground viscous force [4]. However, the development of technological interventions protecting workers, in particular rice farmers, from extreme occupational harm are still rare and limited [9 & 10].

A previous study revealed preliminarily evidence that both rice farmers and CP patients are potentially related in terms of perceived foot and knee soreness and MSDs injuries [11]. Although inherently different in causation, physical disabilities typically associated with CP patients, including knee and foot muscles and joints damage, were also experienced by rice farmers due to the risky environment and unsafe working posture (see detailed investigation in [11]). Likewise, a similarity between the standing posture of CP patients and that of rice farmers during the performance of cultivation activities has been observed, as both population were found to have a high prevalence of knee valgus and foot pronation. Therefore, knee and foot injuries and MSDs should be the main focus of intervention designs in order to avoid the potential risk of lower extremity (LE) harm for paddy farmers. Such interventions could potentially be based on assistive technology previously developed for the CP population. Non-occupational disabilities research can be used as a solid basis for assistive technology (AT) development studies for the agricultural workforce, as available AT designs for the disabled population are already widely available in the commercial market (e.g., back braces, foot orthotics, leg braces, wheelchair, etc.) A broad range of research with focus on AT development for people with disabilities has already been conducted which could also benefit healthy workers exposed to extreme working environments to ease daily life activities or prevent occupational-related injuries (e.g., [12]).

This article aims to provide a constrained review of available interventions for CP disabled people that could be applicable to rice farmers. Ergonomic interventions reviewed in this article were categorized into: (1) engineering, (2) administrative and (3) behavioral control measures [13]. Engineering interventions involve designing systems, equipment or process for eliminating or reducing exposure to dangers (i.e., combining engineering controls and personal protective equipment in the traditional ergonomic/safety preventive measures [14]). Administrative interventions focus on controlling procedures and work practices for example work rotation, task units, and policies. Behavioral interventions, separated from traditional administrative controls in this article, as they concentrate on modifying personal behaviors, which includes behavior support and stress management [13]. Subsequent section provided detailed discussions regarding to adaptability of each intervention in terms of assistance capability, ability improvement and MSD prevention. The intervention types of CP population that might be applicable for farmers were then discussed, along with related intervention examples that had been proposed for reducing risk of injury among paddy field farming workers.

2. Material and Method

In this study, we focused on the literature regarding ergonomic interventions for CP patients. A constrained review was performed using nine article databases, including: "Scopus", "Web of Science", "CINAHL", "Cochrane Database of Systematic Reviews", "Education Source", "ERIC", "Journals@OVID", "MEDLINE", and "PASCAL". Specified terms of "ergonomic interventions", "congenital disability", "cerebral palsy", and "orthoses" were used as search keywords in this study. In the first stage, we recognized 256 pertinent manuscripts which were further refined by the restrictions of being in English language and published within the last 20 years.

Subsequently, two independent reviewers defined whether the articles complied to the inclusion criteria of: (1) the article was a review or the next best available; (2) it contained of ergonomic interventions; and (3) more than 25% of participants were persons with CP. Ergonomic interventions were categorized into control measures involving adjusting workers' environment, tools, work methods and behavior, as well as long-term educational/training approaches to treat and prevent further damage due to MSDs [15]. Finally, after in-depth analysis of abstract and full text articles, 21 articles were included in this study. These comprise 8 papers from Scopus, 4 papers from Web of Science, 4 papers from CINAHL, and 5 papers from MEDLINE. No papers were

met the inclusion criteria in Cochrane, Education Source, ERIC, Journals@OVID, and PASCAL. The whole screening and acceptance process is described in Figure 1.

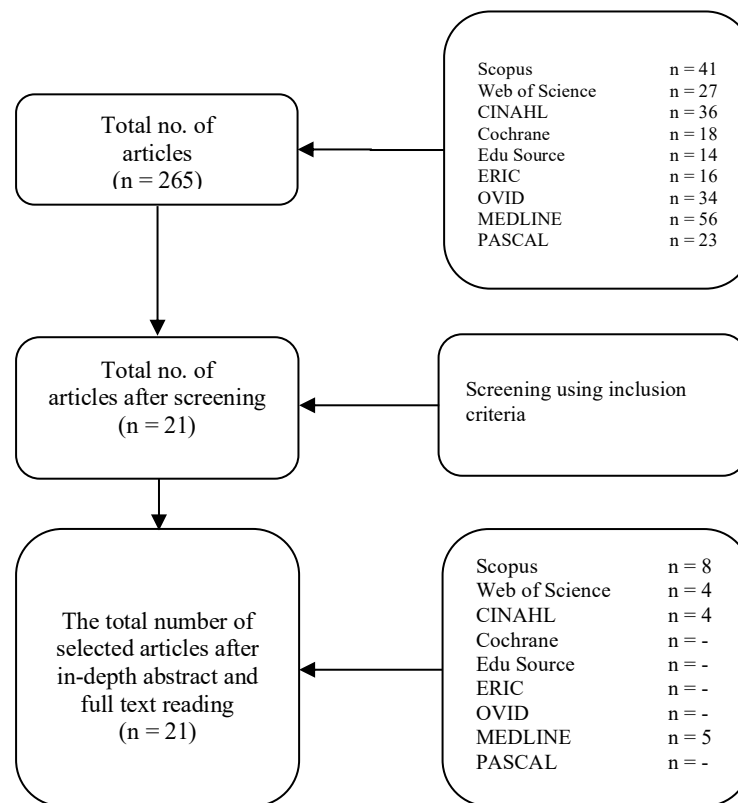


Figure 1 Article screening process

3. Results and Discussion

Selected papers focused on ergonomic interventions for people with CP were reviewed in detail. The results in brief are shown on Tables 1 to 3. Although the prior research showed that farmers and CP patients share similar problems at foot and knee regions, the present review was conducted for the whole body, since some interventions might be adaptable to lower limb parts.

The following subsections discuss interventions for people with CP that could also be applied by healthy rice farmers working in extreme environment to prevent or treat occupation-related injuries. Subsequently, a similar literature search was conducted for interventions that had previously been proposed for rice farmers. Specified terms of “ergonomic interventions”, “rice”, and “paddy” were used as search keywords. Table 4 shows the interventions developed for CP patients that might be adaptable for rice farmers, along with related examples that had been proposed in previous studies.

3.1 Engineering Interventions

Adaptive devices have been shown to be effective in both disabled and aging population [16]. Adaptive devices successfully assist people with disability in functional problems, including difficulty with activities of daily living (ADLs), as evidenced by high percentage improvement of desired outcomes. However, most devices were designed for home use or with environmental modifications (e.g., ramps). Therefore, adaptive devices might not be suitable for the environmental conditions in a paddy field.

Orthotic devices, including casted orthoses, have been demonstrated to successfully enhance the range of motion (ROM) of the lower extremities [17 &18]. However, this type of orthosis is also associated with some adverse effects, including: high price, time-consuming production, difficulty to fit into footwear, skin irritation, foot and calf pain, cast breakdown, and continuing impairment conditions [18,37-39]. Removable external orthotic devices, such as knee braces, ankle foot orthoses (AFO) and knee ankle foot orthoses (KAFO), are generally used to control movement, provide an opposing force, and support ineffective joints or muscles [19]. Previous research found braces to improve gait parameters as compared with standard treatment [19]. However, conventional rigid designs restrict movement as they keep the knee and ankle in a fixed position to provide stability during walking [40]. More recent designs include adaptive control for joint restriction using pneumatic

or electric actuators [20]. However, these are costly, often complicated, and need an external power source [41]. Simple corrective insoles are less expensive and require significantly less time to produce [42]. Previous research showed the corrective insoles to be successfully tested for the treatment of flexible flatfoot [43] and reduction of foot eversion in footwear that has restricted space [44].

Breathable orthotic garment, such as TheraSuit [21], is another possible intervention that has been found to help improve gross motor function without any serious safety issues or skin abrasions reported during the treatment [21]. The suit was originally designed to be worn with bungee cords; however, the additional cords did not add any benefit when compared with wearing the suit alone [21]. Although the suit might provide only small percentage of improvement, noncompulsory requirement of supportive cords contributes a mobility of the device. Therefore, it might represent a possible intervention applicable to farmers performing field work.

Seating and positioning devices enable a person with CP to sit in a comfortable posture and help improving postural control in general [22]. A variant of the device comprising an air inflated seat has been introduced to farmers for postural control during the harvesting process [45].

3.2 *Administrative Interventions*

Educational programs and training, such as manual training, conductive education, and early intervention, developed and successfully improved motor performance and safety for CP patients, may also be applied to rice farmers [23-25]. Regarding the educational programs, prior research [46 & 47] proposed to impart appropriate knowledge and control for safe rice farming work. Health education, as part of the Injury and Illness Preventive (IIP) intervention program [46], was conducted to support risk awareness and to provide safe work conditions during rice field farming. Training provided knowledge regarding work-related injury and illness, and ergonomic guidelines at work (e.g., appropriate work posture, material handling, tool use and working environment). Another part of the IIP program, safety inspection, included a training for inspecting equipment safety and working conditions, in order to help farmers to be able to recognize unsafety behaviors and working environment.

Goal-directed functional training [26] using a motor learning approach might also be beneficial to rice farmers similar to the approach used for CP patients. A previous study reported medium effect size of improvement when comparing goal-directed functional training and physical therapy based on normalization of the quality movement [26]. In a simulated paddy field plowing task, the researcher [48] found experienced farmers to generate higher grip force, to use and balance muscles more effectively, and display a lower fatigue rate, as compared to novice farmers. It was suggested to develop motor learning training for farmers to achieve effective muscle use and minimize risk of injuries.

Fitness and strength training found to significantly improve and maintain physical fitness and muscle strength for CP patients, when compared with regular physical therapy sessions [31& 32]. These specific training programs were also proved to help increasing muscle endurance and physical function, as well as reducing pain in rice farmers with chronic low back pain [49]. Simple physical exercises during the normal work schedule were also proved to reduce musculoskeletal pain [50] and improve the productivity [51]. Massage therapy also found to induce greater reduction in perception of pain and spasticity, as compared with a reading control group of CP patients [29]. Such corrective intervention might also alleviate pain experienced in rice farmers. In addition, manual stretching applied to CP patients to prevent muscle contracture [30], would be applicable to rice farmers. It was suggested to encourage farmers to perform simple stretching exercises during the lunch break. Furthermore, the application of massage therapy was suggested as a practical treatment to help relieve muscle pain and stiffness experienced by farmers [52] as in CP patients [29].

3.3 *Behavioral Interventions*

Caregivers successfully used animal assistance to improve patients' socialization and mood, reduce stress, and assist in ADLs [34]. In the rice cultivation context, paddy field preparation and the threshing process is sometimes conducted with the aid of farm animals [9-10, 53-54]. Besides use of farm animal assistance as a low-cost and environment-friendly farming technique, the farmer's relationship with the animal contributes to the concept of social and economic sustainability [54]. In some communities, farm animals are sometimes given as a gift to relatives, friends or in marriage, and used in religious functions.

Behavior therapy, developed to support positive behavior in children with CPs [35], was identified as another form of possible interventions that could be adapted for promoting safety awareness and behavior for rice farmers. A previous study demonstrated considerable reduction of oppositional behavior of CP children when a family group actively participating in the therapy, as compared with a wait-list control group [35]. Safety communication, as part of the IIP program [46], applied risk communication processes to deliver information regarding possible occupational hazards, health effects and techniques for hazard prevention to rice farmers. Health surveillance programs required paddy field farming workers to report their injury or illness in order to identify the root cause of the incident.

Table 1 Reviews of selected articles - Engineering interventions

No	Intervention	Reference	Outcome
1	Assistive devices: equipment or devices to improve independence, such as walking frames, wheelchairs, adapted computer access	[16]	Improvement of desired outcomes in activities of daily living tasks (PDcontrol = 66%, PDintervention = 75%); slower decline in functional level of independent (PDcontrol = -3.8%, PDintervention = -1.8%)
2	Casting: plaster casts applied to limbs for muscle lengthening or reduce spasticity	[17 & 18]	Improvement of passive range of motion (ROM) of lower limbs and stride length
3	Orthotics: removable external devices designed to support weak or ineffective joints or muscles	[17, 19-20]	Improvement of stride length, ROM and walking distance (RPD =45%), and reduction of abnormal alignment (RPD = -1.1%)
4	Orthotic garments: breathable soft dynamic orthotic full body suit, designed to improve proprioception, reduce reflexes, restore synergies and provide resistance	[21]	Gross motor function improvement (PDcontrol, suit only = 5.9%, PDintervention, suit with supportive cords = 4.5%)
5	Seating and positioning: assistive device that enables a person to sit upright with functional, symmetrical or comfortable posture	[22]	Improvement of posture and postural control

Abbreviations: PD, percentage of difference from baseline; RPD, relative percentage of difference of control vs intervention.

Table 2 Reviews of selected articles – Administrative interventions

No	Intervention	Reference	Outcome
1	Manual training: repetitive task training in the use of one hand or two hands together	[23]	Hand function improvement; reduce time to complete Jebsen-Taylor Test of Hand Function (PDunimanual = -37.8%, PDbimanual = -34.5%)
2	Conductive education (CE): an educational classroom-based approach to teaching movement using rhythmic intention, routines and groups	[24]	Improvement of motor responses (percentage of participants that improved = 23-100%)
3	Early intervention (EI): therapy and early education to promote acquisition of milestones, via group or individual stimulus	[25]	Motor outcomes improvement
4	Goal-directed training/functional training: task specific practice of goal-based activities using a motor learning approach	[26]	Improvement of mobility of functional skill (effect size = 0.61)
5	Hip surveillance: active surveillance and treatment for hip joint integrity to prevent hip dislocation	[27]	Reduction of need for surgery on hip dislocation (requirement of reconstructive surgery reduced from 37.1% to 29%; and salvage surgery reduced from 11.4% to 0%)
6	Home programs: therapeutic practice of goal-based tasks by the child, led by the parent and supported by the therapist, in the home environment	[28]	Improvement of performance of functional activities
7	Massage: therapeutic stroking and circular motions applied by a massage therapist to muscles	[29]	Pain and spasticity reduction (PDcontrol = -9.1%, PDintervention = -33.3%)
8	Stretching: use of an external passive force exerted upon the limb to move it into a new and lengthened position	[30]	Improvement of joint ROM and functional ability
9	Fitness training: planned structured activities involving repeated	[31]	Aerobic fitness improvement (RPD =18-22% for short-term training; RPD = 26-

No	Intervention	Reference	Outcome
	movement of skeletal muscles that result in energy expenditure		41% for long-term training) and increase activity (RPD = 0-13% for short-term training; RPD = 2-9% for long-term training)
10	Strength training: use of progressively more challenging resistance to muscular contraction	[32]	Muscle strength improvement (effect size = 1.16 – 5.27)
11	Treadmill training: walking practice on a treadmill, with and without partial body support	[33]	Improvement of body structures and function, and gross motor function

Abbreviations: PD, percentage of difference from baseline; RPD, relative percentage of difference of control vs intervention.

Table 3 Reviews of selected articles – Behavioral interventions

No	Intervention	Reference	Outcome
1	Animal assistance: use of animals to give companionship and help with independence	[34]	Improvement of mood, behavior and self-perception
2	Behavior therapy: positive behavior support, behavior interventions, and positive parenting	[35]	Reduction of oppositional behaviors (PDcontrol = {-40}-20%, PDintervention = {-75}-{-89.7}%)
3	Respite: temporary caregiving break for parents where the child is usually accommodated outside home	[36]	Reduction of life and parental stress

Abbreviations: PD, percentage of difference from baseline.

Table 4. Possible interventions of CP patients adaptable for rice farmers

Adaptable intervention	Related intervention proposed for rice farmers	Reference
Engineering intervention		
Orthotics	Not have yet implemented	
Orthotic garments	Not have yet implemented	
Seating and positioning	An air inflated pillow, like a floating seat in paddy field harvesting posture	[45]
Administrative intervention		
Bimanual training/ Conductive education/ Early intervention	Health education for rice farmer groups via the Injury and Illness Prevention (IIP) program	[46]
	Safety inspection for rice farmers via the Injury and Illness Prevention (IIP) program	[46]
	Model development for health promotion and control of agricultural occupation health hazards and accidents	[47]
	Not have yet implemented	
Goal-directed training/ Functional training	Not have yet implemented	
Massage	Not have yet implemented	
Stretching	Not have yet implemented	
Fitness training/ Strength training	Intervention based on the Transtheoretical Model (TTM) on back muscle endurance, physical function and pain in rice farmers with chronic low back pain	[49]
Behavioral intervention		
Animal assistance	Paddy field preparation and threshing process were conducted by farm animals (e.g., buffalo, bullock)	[9-10,53-54]
Behavior therapy	Safety Communication for rice farmers via the Injury and Illness Prevention (IIP) program	[46]
	Health surveillance for rice farmer groups via the Injury and Illness Prevention (IIP) program	[46]
	Not have yet implemented	

4. Conclusion

As farmers face severe ergonomic problems physically, assistive tools and proper work process design by considering the ergonomic perspective are urgently needed for MSD prevention in paddy farming workplaces. Farmers experience severe ergonomic problems; for example, MSDs, tool-related accidents and injuries, and lack of safety training. Ergonomic interventions are an effective method for micro-ergonomic occupational related problem prevention. Based on the literature review, engineering and administrative interventions, developed for CP patients, contributed to significantly improvement of motor function and gait characteristics. Behavioral interventions successfully promoted positive emotion and appropriate behavior, as well as reduced stress and oppositional behavior in CP patients. Discussions of adaptability of interventions revealed that a multitude of interventions developed for CP patients might be easily adapted to rice farmers. However, most of the proposed interventions for farmers are based on educational programs, which are closely related to administrative and behavioral interventions. Although in previous research engineering interventions had been developed through tool design for paddy cultivation, including seeding, planting, threshing and harvesting (e.g., [10],[55] and [56]), none of these approaches attempted to adapt already available interventions for congenital disabilities, including CPs, for farmers. Similarly, despite modern harvesting and planting machines have been introduced, limitations for widespread use of such mechanical power still persist, not least due to socio-economic conditions and infra-structural limitations of the society [45 & 57]. Based on interventions that have been applied for CP patients, orthotic devices and breathable orthotic garments might be applicable for rice farmers, however, have not yet been implemented in previous studies.

In summary, farmer interventions should emphasize on both tool design and educational programs. The following key points were recommended to prevent MSDs and improve occupational health and safety in the rice farming industry:

- Design and develop specific job descriptions according to ergonomic guidance;
- Design and develop assistive devices considering ergonomic guidance;
- Promote fitness and strength training, as well as design motor learning training for effective movement;

- Implement assessment tools and reviewing systems for MSD and injury prevention, as well as accident and risk factor reduction among rice farmers;
- Create supportive collaborations with involved farmers through intervention programs and assessments and;
- Support campaign for safety and health programs and drive rice farmers' awareness for work safety.

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References

- [1] Vanderheiden GC, Jordan JB. Design for People with Functional Limitations, in: Salvendy, G. (Ed.), In: Handbook of Human Factors and Ergonomics. Fourth Edition. New York: John Wiley & Sons; 2006. p. 1409–1441.
- [2] Schrank ES, Stanhope SJ. Dimensional accuracy of ankle-foot orthoses constructed by rapid customization and manufacturing framework. *J Rehabil Res Dev*. 2011;48(1):31–42.
- [3] Newell AF, Cairns AY. Designing for extraordinary users. In: *Ergonomics in Design*. 1993. p. 10–6.
- [4] Juntaracena K, Neubert MS, Puntumetakul R. Effects of muddy terrain on lower extremity muscle activity and discomfort during the rice planting process. *Int J Ind Ergon*. 2018;66:187–93.
- [5] Mekkamul P. Ethnobotanical Study of Rice Growing Process in Northeastern, Thailand. *Ethnobot Res Appl*. 2006 Dec 31;4(0):213–22.
- [6] Karukunchit U, Puntumetakul R, Swangnetr M, Boucaut R. Prevalence and risk factor analysis of lower extremity abnormal alignment characteristics among rice farmers. *Patient Prefer Adherence*. 2015;9:785–95.
- [7] Puntumetakul R, Siritaratiwat W, Boonprakob Y, Eungpinichpong W, Puntumetakul M. Prevalence of musculoskeletal disorders in farmers: Case study in Sila, Muang Khon Kaen, Khon Kaen province. *J Med Technol Phys Ther*. 2011;23(3):297–303.
- [8] Karukunchit U, Swangnetr M, Puntumetakul R, Eungpinichpong W, Emasithi A. Prevalence of lower extremity malalignment in rice farmers. In *Proceedings of the 5th International Conference Applied Human Factors Ergonomics 2014*. Krakow, Poland.
- [9] Mamansari DU, Salokhe VM. The need for ergonomics considerations for the design and development of agricultural machinery in Thailand. *J Hum Ergol (Tokyo)*. 1995;24(1):61–72.
- [10] Mohanty SK, Behera BK, Satapathy GC. Ergonomics of Farm Women in Manual Paddy Threshing. *Agric Eng Int CIGR J*. 2008.
- [11] Swangnetr M, Karukunchit U, Juntaracena K, Puntumetakul R, Gross MT, Kaber DB. Relating musculoskeletal and disability conditions of occupation-induced musculoskeletal disorders to nonoccupational congenital disabilities. In *Proceedings of the 7th International Conference on Applied Human Factors and Ergonomics 2016*. Orlando, FL.
- [12] Newell AF, Arnott J, Cairns AY. Ordinary and extra-ordinary HCI. *Usability Now*. (6):191–2.
- [13] Karwowski W, Marras WS. Interventions, Controls, and Applications in Occupational Ergonomics. Crc Press; 2006.
- [14] Tayyari F, Smith JL. Occupational ergonomics: Principles and applications (Manufacturing systems engineering series). United Kingdom: Chapman & Hall London; 1997.
- [15] Kim SE, Junggi H. Ergonomic interventions as a treatment and preventative tool for work-related musculoskeletal disorders. *International Journal of Caring Sciences*, 2013;6(3), 339–348.
- [16] Wilson DJ, Mitchell JM, Kemp BJ, Adkins RH, Mann W. Effects of assistive technology on functional decline in people aging with a disability. *Assist Technol*. 2009 Winter;21(4):208–17.
- [17] Autti-Rämö I, Suoranta J, Anttila H, Malmivaara A, Mäkelä M. Effectiveness of upper and lower limb casting and orthoses in children with cerebral palsy: an overview of review articles. *Am J Phys Med Rehabil*. 2006 Jan;85(1):89–103.
- [18] Blackmore AM, Boettcher-Hunt E, Jordan M, Chan MDY. A systematic review of the effects of casting on equinus in children with cerebral palsy: an evidence report of the AACPD. *Dev Med Child Neurol*. 2007 Oct;49(10):781–90.
- [19] Brouwer RW, Jakma TSC, Verhagen AP, Verhaar J a. N, Bierma-Zeinstra SMA. Braces and orthoses for treating osteoarthritis of the knee. *Cochrane Database Syst Rev*. 2005 Jan 25;(1):CD004020.
- [20] Meyer-Heim A, van Hedel HJA. Robot-assisted and computer-enhanced therapies for children with cerebral palsy: current state and clinical implementation. *Semin Pediatr Neurol*. 2013 Jun;20(2):139–45.
- [21] Bailes AF, Greve K, Burch CK, Reder R, Lin L, Huth MM. The effect of suit wear during an intensive therapy program in children with cerebral palsy. *Pediatr Phys Ther Off Publ Sect Pediatr Am Phys Ther Assoc*. 2011;23(2):136–42.

- [22] Chung J, Evans J, Lee C, Lee J, Rabbani Y, Harris SR, et al. Effectiveness of adaptive seating on sitting posture and postural control in children with cerebral palsy. *Pediatr Phys Ther.* 2008 01;20(4):303–17.
- [23] Brandao M, Gordon AM, Hung Y-C, Brandao M, Friel K, Charles JR. Bimanual training and constraint-induced movement therapy in children with hemiplegic cerebral palsy: a randomized trial. *Neurorehabil Neural Repair.* 2011 Oct;25(8):692–702.
- [24] Darrah J, Watkins B, Chen L, Bonin C. Conductive education intervention for children with cerebral palsy: an AACPD evidence report. *Dev Med Child Neurol.* 2004 Mar;46(3):187–203.
- [25] Blauw-Hospers CH, Hadders-Algra M. A systematic review of the effects of early intervention on motor development. *Dev Med Child Neurol.* 2005 Jun;47(6):421–32.
- [26] Ketelaar M, Vermeer A, 't Hart H, van Petegem-van Beek E, Helders PJM. Effects of a functional therapy program on motor abilities of children with cerebral palsy. *Phys Ther.* 2001 Sep;81(9):1534–45.
- [27] Gordon GS, Simkiss DE. A systematic review of the evidence for hip surveillance in children with cerebral palsy. *J Bone Joint Surg Br.* 2006;(11):1492.
- [28] Novak I, Cusick A. Home programmes in paediatric occupational therapy for children with cerebral palsy: Where to start? *Aust Occup Ther J.* 2006;53(4):251–64.
- [29] Hernandez-Reif M, Field T, Largie S, Diego M, Manigat N, Seoanes J, et al. Cerebral Palsy Symptoms in Children Decreased Following Massage Therapy. *Early Child Dev Care.* 2005 Jul 1;175(5):445–56.
- [30] Wiart L, Darrah J, Kumbhavi G. Stretching with children with cerebral palsy: what do we know and where are we going? *Pediatr Phys Ther Off Publ Sect Pediatr Am Phys Ther Assoc.* 2008 Summer;20(2):173–8.
- [31] Butler JM, Scianni A, Ada L. Effect of Cardiorespiratory Training on Aerobic Fitness and Carryover to Activity In Children with Cerebral Palsy: A Systematic Review. *Int J Rehabil Res.* 2010 Jun 1;33(2):97–103.
- [32] Dodd KJ, Taylor NF, Damiano DL. A systematic review of the effectiveness of strength-training programs for people with cerebral palsy. *Arch Phys Med Rehabil.* 2002;(8):1157.
- [33] Zwicker JG, Mayson TA. Effectiveness of treadmill training in children with motor impairments: an overview of systematic reviews. *Pediatr Phys Ther Off Publ Sect Pediatr Am Phys Ther Assoc.* 2010 Winter;22(4):361–77.
- [34] Munoz Lasa S, Valero R, Ferriero G, Franchignoni F, Brigatti E. Animal-assisted interventions in internal and rehabilitation medicine: a review of the recent literature. *Panminerva Med.* 2011 Jun;53(2):129–36.
- [35] Roberts C, Mazzucchelli T, Studman L, Sanders MR. Behavioral Family Intervention for Children with Developmental Disabilities and Behavioral Problems. *J Clin Child Adolesc Psychol.* 2006 Jan 1;35(2):180–93.
- [36] Julie A. S. Respite Care for Families of Special Needs Children: A Systematic Review. *J Dev Phys Disabil.* 2010;(6):615.
- [37] Chapman C. Chairside orthoses—the end of casting? *Podiatry Now.* 04:1999.
- [38] Cottalorda J, Gautheron V, Metton G, Charmet E, Chavrier Y. Toe-walking in children younger than six years with cerebral palsy. *J BONE Jt Surg.* 2000;82-B(4):541–544.
- [39] Watt J, Sims D, Harcham F, Schmidt L, McMillan A, Hamilton J. A prospective study of inhibitive casting as an adjunct to physiotherapy for cerebral-palsied children. *Dev Med Child Neurol.* 1986 Aug;28(4):480–8.
- [40] Yakimovich T, Lemaire ED, Kofman J. Engineering design review of stance-control knee-ankle-foot orthoses. *J Rehabil Res Dev.* 2009;46(2):257–67.
- [41] Cullell A, Moreno JC, Rocon E, Forner-Cordero A, Pons JL. Biologically based design of an actuator system for a knee–ankle–foot orthosis. *Mech Mach Theory.* 2009 Apr 1;44(4):860–72.
- [42] McCourt FC. To cast or not to cast? The comparative effectiveness of casted and non casted orthoses. *The Chiropodist.* 1990;45:239–243.
- [43] Chen MJ, Chen CP, Lew HL, Hsieh WC, Yang WP, Tang SF. Measurement of forefoot varus angle by laser technology in people with flexible flatfoot. *American journal of physical medicine & rehabilitation.* 2003 Nov 1;82(11):842–6.
- [44] Branthwaite HR, Payton CJ, Chockalingam N. The effect of simple insoles on three-dimensional foot motion during normal walking. *Clin Biomech Bristol Avon.* 2004 Nov;19(9):972–7.
- [45] Nag PK, Goswami A, Ashtekar SP, Pradhan CK. Ergonomics in sickle operation. *Appl Ergon.* 1988 Sep;19(3):233–9.
- [46] Santaweek S, Chapman RS, Siri Wong W. Effects of an injury and illness prevention program on occupational safety behaviors among rice farmers in Nakhon Nayok Province, Thailand. *Risk Manag Healthc Policy.* 2014 Mar 8;7:51–60.
- [47] Buranatrevedh S, Sweatsriskul P. Model development for health promotion and control of agricultural occupational health hazards and accidents in Pathumthani, Thailand. *Ind Health.* 2005 Oct;43(4):669–76.

- [48] Swangnetr M, Kaber D. Analysis of grip force and arm muscle activity between novice and experienced rice farmers in plowing task. In: The 5th International Conference on Applied Human Factors and Ergonomics. Krakow, Poland; 2014.
- [49] Thanawat T, Nualnetr N. Effects of an intervention based on the Transtheoretical Model on back muscle endurance, physical function and pain in rice farmers with chronic low back pain. *J Back Musculoskeletal Rehabil.* 2017;30(4):847–56.
- [50] Lee KS, Waikar A. Types of activities and body parts affected in the recommended exercises for VDT operators. *J Hum Ergol (Tokyo).* 1991 Jun;20(1):13–26.
- [51] Balci R, Aghazadeh F. The effect of work-rest schedules and type of task on the discomfort and performance of VDT users. *Ergonomics.* 2003 Apr 15;46(5):455–65.
- [52] Keawduangdee P, Puntumetakul R, Swangnetr M, Laohasiriwong W, Settheetham D, Yamauchi J, Boucaut R. Prevalence of low back pain and associated factors among farmers during the rice transplanting process. *Journal of Physical Therapy Science,* 2015;27, 2239-2245.
- [53] Joshi SK. Rice field work and the occupational hazards. *Occu- Med.* 2002;4:111–4.
- [54] Nanda AS, Nako T. Role of buffalo in the socioeconomic development of rural Asia: Current status and future prospectus. *Animal Science Journal,* 2003;74(6), 443-455.
- [55] Khayer SM, Patel T, Kn D. Ergonomic Design Improvement of Pedal Thresher: An Approach Combining Digital Human Modelling and Response Surface Analysis. *J Ergon.* 2017;7(6):1–9.
- [56] Swangnetr M, Kaber D, Phimphasak C, Namkorn P, Saenlee K, Zhu B, et al. The influence of rice plow handle design and whole-body posture on grip force and upper-extremity muscle activation. *Ergonomics.* 2014;57(10):1526–35.
- [57] Ojha P, Kwatra S. Analysis of different paddy transplanting methods in northern India: Ergo - economical study. *J Appl Nat Sci.* 2014;6(2):654–8.

Work Postural and Environmental Factors for Lower Extremity Pain and Malalignment in Rice Farmers

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Abstract. In many Southeast Asian Countries, most tasks of the rice cultivation rely heavily on manual labor and require prolonged working in muddy terrain. Due to the lack of comprehensive ergonomic assessment and interventions, a series of studies were conducted to examine work postural and environmental factors contributing to lower extremity (LE) pain and malalignment in Thai rice farmers. This paper evaluates the collective results of our previous studies, which can be divided into two stages. The initial stage included a survey of pain perception and physical examination of LE alignment to specify the most problematic LE parts in a large group of 250 farmers, revealing that farmers generally perceived elevated hip pain. However, physical examination identified a high prevalence of foot pronation and knee valgus. A subsequent detailed analytical stage, conducted to identify factors of LE pain on a smaller group of 30 farmers, included two-stage ergonomic risk assessment and investigation of effects of muddy work terrain in different laboratory settings. The ergonomic assessment results indicated the planting process to pose the highest risk for LE injury, specifically leading to perception of knee pain induced by motion and posture factors, and foot pain induced by force exertion. Experiential results showed muddy ground to induce significantly higher force on knees and higher levels of knee and ankle muscle exertion. The findings suggest that further development of interventions should focus on reducing awkward posture and muscular exertion due to mud resistive force, particularly for knee and foot during the planting process.

Keywords: Lower Extremity Pain, Risk Assessment, Muddy Work Environment, Muscle Activity, Rice Cultivation Process.

1 Introduction

Agricultural work has been known to pose ergonomic hazards due to requiring repetitive force exertion and awkward postures [1-2]. In Thailand and many Southeast Asian Countries, the rice production industry generates a significant market volume of agricultural products [3]. With the increase in production demands and concomitant lack of technological interventions for the majority of the workforce, farmer health and safety has become a key factor to ensure high efficiency and productivity of the agricultural sector. The rice cultivation process involves multiple stages, including field preparation, seeding, planting, nursing and fertilization, and harvesting [4]. Most tasks rely heavily on strenuous manual efforts and require prolonged working in muddy terrain. Such viscous muddy environment causes farmers to preferably perform tasks without footwear. As a result of these extreme work conditions, a previous study indicated a high prevalence of musculoskeletal disorder (MSD) in the lower extremities (LE) among Thai rice farmers (10.29–41.16%) [5]. LE MSDs have been found to cause chronic leg pain and may promote the development of LE malalignment [6-7]. Clearly, such detrimental health conditions severely impact the working capability and require costly medicine and healthcare service.

Although epidemiological studies of the prevalence of LE pain among rice farmers have already been reported [5], there is still a lack of comprehensive ergonomics assessment and intervention programs for rice farmers. Therefore, we conducted a series of studies to examine work postural and environmental factors contributing to LE pain and malalignment in Thai rice farmers. This paper aims to present a comprehensive assessment of the collective results of our previous studies, which can be divided into two stages (see Fig. 1). An initial stage included a survey of pain perception and physical examination of LE alignment to specify the most problematic LE parts. The subsequent detailed analytical stage, conducted to identify factors of LE pain, included two-stage ergonomic risk assessment and investigation of effects of muddy work terrain in different laboratory settings. The objectives of this study were to specify the most problematic LE parts and to identify factors of LE pain of rice farmers. The implications of this research are anticipated to benefit the development of work guidelines and interventions for rice farmers that minimize specified risk factors of the LE parts, of which pain and malalignment are of most concern.

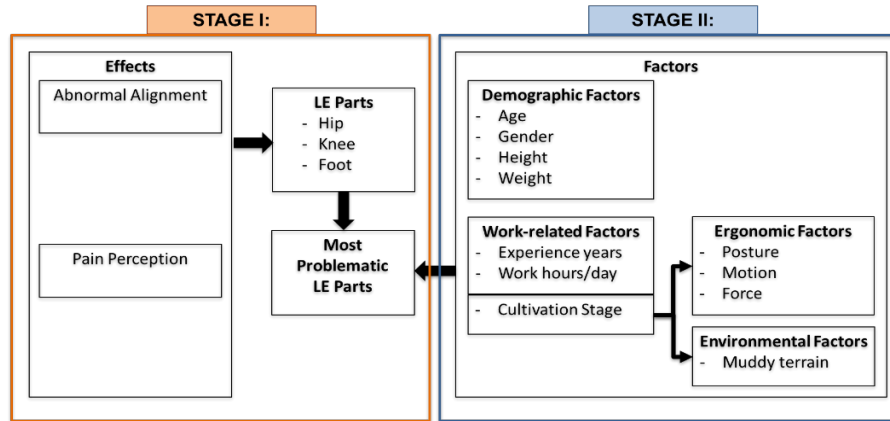


Fig. 1. Overall study framework

2 Methods and Results of Stage I

2.1 Participants

Two hundred and fifty (250) experienced rice farmers (108 male and 142 female farmers with age between 20-59 years) in rice farming villages located in Sila district, Khon Kaen Province, were recruited to participate in the study. Participants were required to have at least one year of experience in rice cultivation. One participant was excluded from the study due to the following exclusion criteria: 1) chronic leg and foot pain within two weeks prior to testing, such as gouty arthritis, rheumatoid arthritis, or ankylosing spondylitis; 2) previous or current injury to the lower extremities or; 3) any previous history that would affect lower extremity alignment, such as a fracture and/or surgery.

2.2 Examination of LE Malalignments

LE alignment measurements examined in our study [8] included pelvic angle, femoral antetorsion, quadriceps (Q) angle, tibiofemoral angle, genu recurvatum, tibial torsion, rearfoot angle, and medial longitudinal arch angle. All measurements were repeated 3 times by a single examiner who had excellent test-retest reliability on all lower extremity measures (ICC range of 0.89-0.98). Participants were asked to wear shorts that exposed lower limb parts for testing. Abnormal ranges of alignment were subsequently classified into malalignment characteristics of hip (anterior pelvic tilt, posterior pelvic tilt and excessive femoral antetorsion), knee (genu valgus, genu varus, knee hypertension and tibial torsion) and foot (pronate and supinate foot). The details of LE alignment measurement and classification methods were described in [8].

The average of three LE alignment measurements was used for analyses. The findings (see Table 1) indicated foot and knee malalignment to be common among Thai

rice farmers. The prevalence of LE malalignments of rice farmers was found to be highest for foot pronation (36.14%), followed by knee valgus (34.94%). The highest malalignment characteristics of hip was found in terms of anterior pelvic tilt (30.52%). No posterior pelvic tilt and supinate foot conditions were observed in this study.

Table 1. Prevalence of LE malalignment

Malalignment characteristics	Number	%
Anterior pelvic tilt	76	30.52
Excessive femoral antetorsion	70	28.11
Knee valgus	87	34.94
Knee varus	77	30.92
Knee hyperextension	28	11.24
External tibial torsion	53	21.29
Foot pronation	90	36.14

2.3 Survey of LE Pain Perception

LE pain investigation was conducted to compare pain perceived by rice farmers for each cultivation step. Rice farmers were asked to rate the Thai version of the Visual Analog Scale (VAS) using a body chart region modified from the Standardized Nordic Questionnaire [9] for LE part discomfort before and after each farming stage for the complete cultivation cycle. The VAS for pain rating scales ranged from 0 to 10 points, where 0 represents no pain and 10 was intolerable pain.

Results of perceived pain ratings for each LE parts for rice farmers in each cultivation steps are shown in Fig. 2. Analysis of Variance (ANOVA) demonstrated that rice farmers perceived significantly greater LE pain during performance of rice cultivation tasks than before the cultivation activity. Pain rating results further indicated that farmers perceived the highest LE pain during the planting task. Results of paired t-test comparing each LE part revealed that, in general, farmers perceived higher pain in the hip, as compared with knee and foot.

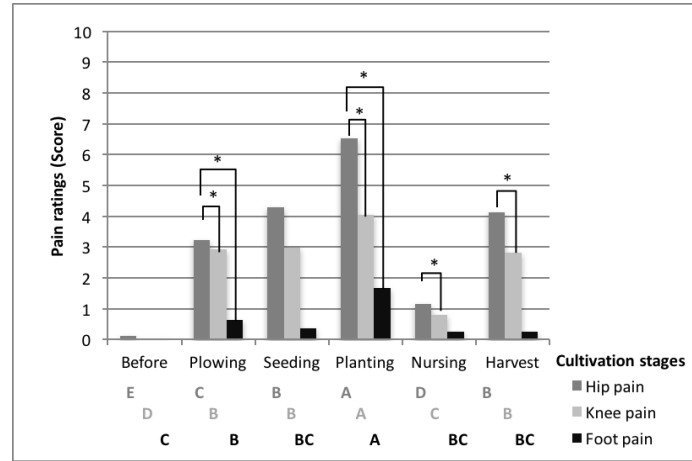


Fig. 2. Results of LE pain for each cultivation stage (Mean with the asterisk (*) and different letters are significantly different at $\alpha = 0.05$)

2.4 Problematic LE Parts

Although rice farmers experienced less knee and foot pain during cultivation activities, malalignment examination results indicated higher prevalence in foot pronation and knee valgus. Excessive foot pronation may also originate from other malalignment conditions, including excessive internal femoral rotation, external tibial rotation or anterior pelvic tilt position [10-11], which might contribute to hip muscle pain [12]. Therefore, all LE parts were still considered for further investigation in subsequent detailed analyses.

3 Methods and Results of Stage II

3.1 Participants

The same set of 250 participants was used to identify risk factors of LE abnormal alignments. For detailed analyses of ergonomic risk and environmental factors, a smaller group of 30 farmers was randomly selected to participate in the experiments.

3.2 Risk Factor Identification of LE Malalignments

Analysis of demographic factors (age, gender and body mass index (BMI)) and work-related factors (average working hours per day and years of work experience) for LE malalignments was conducted for 250 rice farmers in our previous study [8]. The objective of the analysis was to investigate whether common malalignment conditions among farmers were caused by performing farming activities. This paper presents only specific malalignment conditions of: anterior pelvic tilt, knee valgus and foot pronation, since these conditions were found to be associated with the highest prevalence of hip,

knee and foot, respectively. Table 2 indicates female gender to correlate (increased risk) with abnormal Q angle and tibiofemoral angle. Overweight individuals were associated with abnormal pelvic tilt angle, Q angle and tibiofemoral angle. Number of years of farming experience was associated with abnormal Q angle, tibiofemoral angle, and foot alignment. Every increase of 1 year of farming work increased the odds ratio for abnormal angle of knee and foot by 4 - 6%.

Table 2. LE malalignments and related factors in multiple logistic regression analysis

Factors	Adjusted Odds Ratio (95% Confidence Interval)			
	Pelvic tilt angle	Q angle	Tibiofemoral angle	Foot alignment
Sex: Female	1.70 (0.88-2.37)	2.40 (1.32-4.39)*	1.90 (1.03-3.51)*	
BMI: Overweight	8.6 (4.7-16.15)*	1.94 (1.07-3.55)*	2.05 (1.11-3.78)*	1.56(0.87-2.81)
Age	1.03 (0.99-1.07)			
Daily working hours		1.18 (0.91-1.51)	1.23 (.95-1.58)	
Years of experience		1.04 (1.01-1.08)*	1.04 (1.01-1.08)*	1.06 (1.03-1.1)*

Note: * indicates a significance at $p < 0.05$.

3.3 Ergonomic Risk Factor Identification of LE Pain

The two-stage ergonomic risk assessment included first-stage worst case risk assessment and the second-stage risk assessment for 30 individual participants based on the highest-risk subtask (see detailed in [13]). The assessments were conducted independently by 3 expert analysts based on direct and video-based observation during task performance in each stage of the rice cultivation. The evaluation method was based on the modified Rapid Upper Limb Assessment (RULA) [14] tool with an extension to cover whole body parts for ergonomic risks in terms of improper posture, motion and force. In line with the previous analysis of pain, ANOVA results also indicated the planting process to pose the highest ergonomic risk for LE injury in rice farmers ($p < 0.0001$).

Subsequent multiple linear regression analyses were conducted to identify ergonomic risk factors associated with LE pain during the planting process. Unfortunately, hip pain did not establish a linear relationship with risk factors ($p > 0.05$, $R^2 < 0.3$). Therefore, a more detailed investigation of the complex relationship between these factors using a non-linear modelling approach will be required in future studies. For other significantly associated factors of perceived pain, results showed knee pain perception to be significantly induced by motion and posture factors ($p = 0.017$ and 0.008 , respectively); while foot pain perception was primarily caused by force exertion ($p = 0.014$).

3.4 Environmental Factor Identification of LE Pain

A unique work condition encountered in rice cultivation results from most tasks being typically performed with bare feet in muddy terrain. Such working environments might lead to increasing both the force acting on joints as well as the muscular force requirements in the LEs of farmers, which increase due to force resulting from body weight

and mud viscosity [15]. The environmental factor of muddy work terrain was investigated in a group of 30 participants during the simulated planting setup on rigid and muddy work surface. A specific posture, involving lifting one foot off the work surface, was selected due to strong association with tensile viscous force. A 3D Static Strength Prediction Program (3DSSPP; Center of Ergonomics, University of Michigan ref) was used to estimate tensile force loading on the LE joints. Muscle activity was captured using electromyography (EMG) during a 10-session simulated task. Both investigations were conducted for only one side of the legs. Details of 3DSSPP analysis and muscle activity analysis along with laboratory settings were described in [16] and [17], respectively. According to 3DSSPP computation results, the knee joint was found to be exposed to the greatest force increase due to mud resistance (see Fig. 3). Results of repeated measure ANOVA of EMGs (see Fig. 4) showed muddy ground to induce significantly higher levels of biceps femoris (BF; knee flexor) and gastrocnemius (GA; ankle plantar flexor) muscle exertion, as compared with rigid ground.

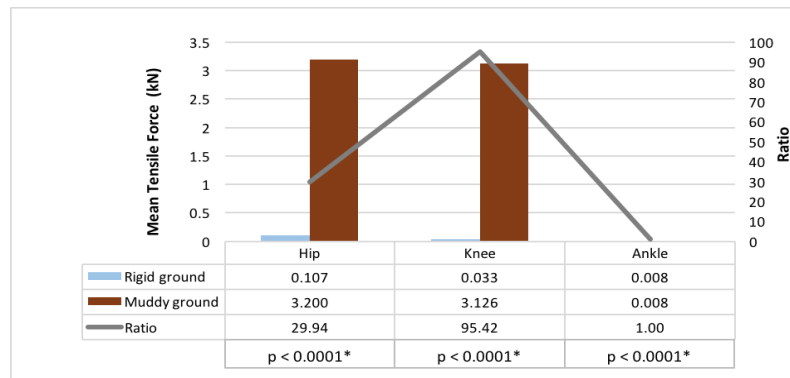


Fig. 3. Results of force on LE joints for muddy and rigid ground conditions.

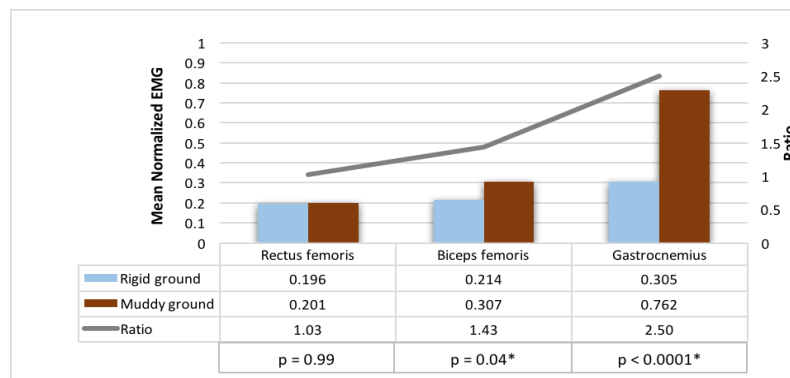


Fig. 4. Results of LE muscle activity for muddy and rigid ground conditions.

4 Discussion

The study found the highest prevalence of LE malalignments among rice farmers in foot pronation, followed by knee valgus. The highest malalignment characteristics for the hip was found in terms of anterior pelvic tilt. These conditions might be associated to each other. Excessive foot pronation may be a result of knee valgus or anterior pelvic tilt position [10-11]. Also, abnormal knee alignment may be caused by hip, ankle, or foot malalignment [18-19]. Detailed analysis of risk factors showed this specific type of hip and knee malalignments to be associated with individual factors of BMI. Overweight individuals have a high risk for developing abnormal pelvic tilt angle, Q angle and tibiofemoral angle, since an increase in joint loading can produce injury to weight-bearing joints of the LEs [20-21]. Knee malalignment was also found to be associated with gender. Female individuals were found prone to increased risk of abnormal Q angle and tibiofemoral alignment. Knee malalignment in females may result from wider pelvic width and amplified internal rotation of the hips, as compared with males [22]. Moreover, female individuals on average have lower knee muscle strength, which may lead to excessive abnormal loading on the knee joint, in turn leading to knee malalignment [23-24].

The work-related factor of years of farming experience was found to be associated with knee and foot malalignments. However, hip malalignment could not be proved to relate to rice farming experience. Since most farming tasks are performed in awkward postures with repetitive LE motion and involving heavy loads, lifting or carrying excessive weight may overload muscles and tendons of knee and foot [1, 21]. Exposure to such working conditions was found to be associated with degeneration of joints, which is a risk factor for malalignment [1]. Repetitive awkward postures, such as stooping and twisting, are associated with chronic knee musculoskeletal symptoms. As a result, increased abnormal knee loading may lead to injury, such as osteoarthritis (OA) and patellofemoral pain syndrome, and might develop into knee malalignment [18-19]. Moreover, farming activities also involved working on slippery uneven surface of muddy terrain. Such environmental conditions may be challenging for farmers to control leg alignment and may lead to increased foot and knee pain arising from postural instability and fatigue [25]. Years of exposure to such risk factors could lead to progressive abnormal biomechanical function and result in increasing risk of LE malalignments [18-19].

Contrary to the malalignment examination, pain analysis results showed that farmers perceived higher pain in the hip, as compared with knee and foot. As mentioned previously, hip pain due to malalignment may originate from foot pronation and knee valgus [12]. However, analyses using linear models could not establish strong relationships between ergonomic risk factors and hip pain. With regard to the cultivation stages, the study showed that rice farmers perceived the highest LE pain during the planting task. Detailed analyses indicated that, for the planting stage, perceived knee pain was significantly induced by motion and posture factors, while foot pain perception was primarily caused by force exertion. During the planting activities, the typical farming work posture constitutes a combination of squatting, forward bending and rotation of the trunk, assumed for several hours during a work shift. These activities were

found to induce knee discomfort, especially in the hamstring muscle group, as a result of maintaining stooped postures leading to overuse and fatigue of affected knee muscles [26]. With respect to foot pain perception induced by the force factor, performing planting work while carrying heavy load on a muddy walking surface was found to create excessive loading on trunk and foot muscles [1].

To further investigate the force factor due to the adverse environmental conditions of muddy work terrain, a simulated rice planting task was conducted to compare the force acting on joints as well as the muscular force requirements to the LEs of farmers on muddy vs. rigid working surface. Experiment results revealed BF and GA muscle activities to significantly increase when participants were working on muddy ground in comparison with the rigid ground condition. Participants utilized higher activity levels of a certain set of BF and GA muscles to compensate for mud viscous force. An increase in BF and GA activity, which assisted knee flexion, was in line with results from the biomechanical model estimation of tensile force loading on LE joints, indicating the knee is exposed to the highest force increase due to mud viscosity. Substantially higher GA activity might result from a higher propulsion force from plantar flexion required for backward gait initiation. Such high GA activity requirements also complement the result of foot pain perception induced by excessive force. Prolonged repetition of GA exertion might lead to muscle fatigue and increase of risk of structural malalignment of the feet [25], which correlates well with the high prevalence of abnormal alignment found in foot condition.

5 Conclusion and Future Research

The collected results of our studies revealed the knee and foot to be priority LE parts that need to be addressed due to the high prevalence of knee valgus and foot pronation. The environment condition of muddy work terrain also increased force loading on the knee and foot joints and muscles due to adverse effects of ground viscous force on the legs. Although the hip was found to be the most problematic part in terms of pain perception, there is currently no evidence of relationships between hip pain and rice cultivation activities. Moreover, hip pain might be attributed to abnormal alignments of foot and knee. Based on these findings, future research should emphasize on developing self-care programs, personal protective equipment and/or assistive devices to prevent knee and feet injury during rice planting task performance. More specifically, the development of protective and assistive interventions should focus on reducing awkward posture and repetitive motion of the knee, and on alleviating forceful exertion of knee and foot during work on muddy terrain. Self-care programs should be designed to develop self-awareness of improper work postures, excessive load and repetitive movement, and to implement exercises that focus on strengthening the hamstring group and gastrocnemius muscles.

Regarding future research in our group, a particular focus is set on designing customized footwear with medical wedging at various places underneath the foot to reduce eversion. Such footwear is anticipated to have beneficial impact on preventing knee arthritis attributable to knee valgus as well as soft tissue and joint injuries of the foot

and ankle secondary to foot pronation. In addition, the use of skin-comfort materials will be investigated where the footwear contacts the skin. The resulting footwear designs are expected to be useable alongside with adaptive knee braces, which can be manually or automatically locked to prevent or support specific motions and work postures. Such a design concept may also be applicable for farmers, who demonstrate excessive foot pronation and knee valgus due to the extreme work conditions in the field, by incorporating materials that may help reduce mud viscous force for footwear shells.

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References

1. Reid, C. R., Bush, P. M., Karwowski, W., Durrani, S. K.: Occupational postural activity and lower extremity discomfort: a review. *International Journal of Industrial Ergonomics* 40(3), 247-256 (2010).
2. Fathallah, F. A.: Musculoskeletal disorders in labor-intensive agriculture. *Applied Ergonomics* 41(6), 738-743 (2010).
3. Ministry of Commerce of Thailand. Thailand trading report (agricultural products), http://www.ops3.moc.go.th/menucomen/export_topn_re/report.asp, last accessed 2018/04/18).
4. Mokkamul, P.: Ethnobotanical study of rice growing process in northeastern, Thailand. *Ethnobotany Research and Applications* 4, 213-222 (2006).
5. Puntumetakul, R., Siritariwat, W., Boonprakob, Y., Eungpinichpong, W., Puntumetakul, M.: Prevalence of musculoskeletal disorders in farmers: Case study in Sila, Muang Khon Kaen, Khon Kaen province. *Journal of Medical Technology and Physical Therapy* 23(3), 297-303 (2011).
6. Osborne, A., Blake, C., Fullen, B. M., Meredith, D., Phelan, J., McNamara, J., Cunningham, C.: Risk factors for musculoskeletal disorders among farm owners and farm workers: a systematic review. *American Journal of Industrial Medicine* 55(4), 376-389 (2012).
7. Woolf, A. D., Pfleger, B.: Burden of major musculoskeletal conditions. *Bulletin of the World Health Organization* 81(9), 646-656 (2003).
8. Karukunchit, U., Puntumetakul, R., Swangnetr, M., Boucaut, R.: Prevalence and risk factor analysis of lower extremity abnormal alignment characteristics among rice farmers. *Patient Preference and Adherence* 9, 785-795 (2015).
9. Saetan, O., Khiewyoo, J., Jones, C., Ayuwat, D.: Musculoskeletal disorders among north-eastern construction workers with temporary migration. *Srinagarind Medical Journal (SMJ)* 22(2), 165-173 (2010).
10. Khamis, S., Yizhar, Z.: Effect of feet hyperpronation on pelvic alignment in a standing position. *Gait & Posture* 25, 127-134 (2007).
11. Barwick, A., Smith, J., Chuter, V.: The relationship between foot motion and lumbopelvic-hip function: a review of the literature. *The Foot* 12, 224-231 (2012).
12. Chuter, V. H., Janse de Jonge, X.: Proximal and distal contributions to lower extremity injury: a review of the literature. *Gait and Posture* 36, 7-15 (2012).

13. Neubert, M. S., Karukunchit, U., Puntumetakul, R.: Identification of influence demographic and work-related risk factors associated to lower extremity pain perception among rice farmers. *Work: A Journal of Prevention, Assessment and Rehabilitation* 58, 489-498 (2017).
14. McAtamney, L., Corlett, E. N.: RULA: a survey method for the investigation of work-related upper limb disorders. *Applied Ergonomics* 24(2), 91-99 (1993).
15. Tropea, C., Yarin, A. L., Foss, J. F.: *Springer handbook of experimental fluid mechanics* (Vol. 1). Springer Science & Business Media (2007).
16. Juntaracena, K., Swangnetr, M.: Effects of muddy work terrain on force of rice farmer lower extremity joints during rice planting process. In: *Proceedings of the 4th IIAE International Conference on Industrial Application Engineering*. Beppu, Japan (2016).
17. Juntaracena, K., Neubert, M. S., Puntumetakul, R.: Effects of muddy terrain on lower extremity muscle activity and discomfort during the rice planting process. *International Journal of Industrial Ergonomics* 66, 187-193 (2018).
18. Daneshmandi, H., Saki, F., Shahheidari, S., Khoori, A.: Lower extremity malalignment and its linear relation with Q angle in female athletes. *Procedia- Social and Behavioral Sciences* 15, 3349-3354 (2011).
19. Shultz, S. J., Nguyen, A., Levine, B. J.: The relationship between lower extremity alignment characteristics and anterior knee joint laxity. *Sports Health* 1(1), 54-60 (2009).
20. Viester, L., Verhagen, E. A., Hengel, K. M. O., Koppes, L. L., van der Beek, A. J., Bongers, P. M.: The relation between body mass index and musculoskeletal symptoms in the working population. *BMC Musculoskeletal Disorders* 14(1), 238 (2013).
21. Messing, K., Tissot, F., Stock, S.: Distal lower-extremity pain and work postures in the Quebec population. *American Journal of Public Health* 98(4), 705-713 (2008).
22. Nguyen, A. D., Shultz, S. J.: Sex differences in clinical measures of lower extremity alignment. *Journal of Orthopaedic & Sports Physical Therapy* 37(7), 389-398 (2007).
23. Keogh, E., Herdenfeldt, M.: Gender, coping and the perception of pain. *Pain* 97, 195-201 (2002).
24. Scerpella, T. A., Stayer, T. J., Makhuli, B. Z.: Ligamentous laxity and noncontact anterior cruciate ligament tear: a sex-based comparison. *Orthopedics* 28, 656-660 (2005).
25. Nguyen, A. D., Shultz, S. J.: Identifying relationships among lower extremity alignment characteristics. *Journal of Athletic Training* 44, 511-518 (2009).
26. Meyer, R. H., Radwin, R. G.: Comparison of stoop versus prone postures for a simulated agricultural harvesting task. *Applied Ergonomics* 38(5), 549-555 (2007).