Ergonomics
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/terg20

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Published online: 15 Jul 2014.

Ergonomics, 2014
Vol. 57, No. 10, 1526–1535, http://dx.doi.org/10.1080/00140139.2014.934301

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(*Received 10 July 2013; accepted 3 June 2014*)

A previous job screening study revealed ergonomics risk factors in rice field plowing. This work motivated the present experimental investigation of the influence of plow handle design and farmer whole-body posture on grip force and arm muscle activity. A total of 24 experienced farmers performed a simulated plowing task, including walking on even and uneven ground while rolling a tiller equipped with conventional horizontal and proposed vertical handles. Results revealed the proposed handles, designed to promote neutral wrist posture, to increase upper-arm muscle use between 47% and 70% across ground types, as compared with conventional handles. The ratio of grip force to forearm muscle activity (or efficiency in muscle use) increased from 1.85 when using conventional handles on uneven ground to 2.16 when using the proposed handles with symmetrical body posture on even ground. However, participants perceived higher discomfort when using the proposed handles, as they were accustomed to the conventional design.

Practitioner Summary: The findings of this work may be used to educate farmers on the potential for hand and arm injury in rice cultivation activities. Results may also provide a basis for redesign of existing tiller handles to promote neutral wrist posture, greater efficiency in muscle use and machine control.

Keywords: tool handle design; grip force; muscle activity; whole-body posture; body part discomfort

1. Introduction

Thailand is the largest rice exporter in the world (Office of Agricultural Economics Thailand 2013). Recently, there has been an increase in demand for high-quality rice in African and Southeast Asian markets, in part, due to trade liberalisation through the developing ASEAN (Association of Southeast Asian Nations) Economic Community. Consequently, Thai rice farmers' health and safety have become an important issue in order to ensure a sufficient workforce to address the increase in rice production. Musculoskeletal disorders (MSDs) remain the most common non-fatal occupational injury and illness for agricultural workers (Fathallah 2010; Kirkhorn, Earle-Richardson, and Banks 2010). The prevalence of upper-extremity pain in Thai rice farmers has been found to be high for some body parts (relative to non-occupational populations), including: 36.01% for the shoulders, 5.79% for the elbows and 12.54% for the wrists (Puntumetakul et al. 2011).

Field preparation is the first step in rice cultivation. Fields are plowed in multiple stages. During a three-month period in each year, farmers use heavy machinery, such as power tillers, for at least 2 hours per day before taking a break. A previous survey by the National Statistical Office of Thailand (2008) indicated approximately 3.6 million power tillers to be in use in Thailand for rice farming. We previously conducted a task analysis and screening of rice plowing processes for ergonomics risk factor identification (Swangnetr et al. 2012). The job screening method was based on an 'Industrial Ergonomics Screening Tool' developed by the Ergonomics Center of North Carolina, considering high body forces, repetitive movement and awkward postures observed in tasks. The tool was developed based on the Hand Activity Level (HAL; Armstrong 2006) measure and Rapid Upper Limb Assessment (RULA; McAtamney and Corlett 1993) methodology. The screening tool was applied in a lab setting by at least two expert analysts (ergonomists and physiotherapists) for each of the subtasks of rice plowing process. The analysts viewed multiple videos of farmers performing the subtasks. The experts rated exposure to each risk factor for each body part using a 10-point scale. The ratings were subsequently categorised as representing 'low', 'medium' or 'high' risks and aggregated across analysts. Sufficient ratings were recorded to ensure statistical reliability of the results. Results revealed farmers to be exposed to high risk of MSDs from repetitive movement and awkward posture of upper and lower extremities as well as the low back during plowing and clearing debris from a mechanical plow. The highest risk of injury was for the hands and wrists due to plowing with awkward postures, specifically shoulder abduction and extreme ulnar deviation at the wrist. These postures occurred due to a horizontal plow handle

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design, which is a general design found on mechanical plows in Thailand. Such postures, including wrist deviations due to radial and ulnar bending (Armstrong et al. 1982; Hazelton et al. 1975) or flexion and extension (Smith, Sonstegard, and Anderson 1977), along with pinch grips, have been found to be associated with a variety of upper-extremity MSDs (Armstrong 1990). Beyond this, asymmetrical farmer whole-body postures were observed when walking on uneven ground with one foot in a furrow behind a tiller, leading to an imbalance in loading among the hands, feet and limbs. Asymmetrical postures were also found to produce shoulder abduction, awkward elbow postures due to extreme pronation and/or supination of the forearm, and extreme ulnar deviation of the wrist during the task. Such work conditions have previously been found to lead to hand and wrist pain (NIOSH 2001) as well as MSDs (Armstrong et al. 1993; Kattel et al. 1996; Walker-Bone and Palmer 2002).

Wrist and whole-body posture may also influence machine control performance. Such control is critical to farmer safety, specifically preventing injury due to exposure to moving parts. Farmer control of power tillers is primary indicated by maximum grip force generated at handles (Kattel et al. 1996). Tool design and task factors have been found to influence grip force under various work conditions. In general, investigations have observed a near-neutral wrist posture to allow for maximum grip strength. Deviations of the wrist from the neutral posture led to reductions in individual finger forces exerted on objects (Fong and Ng 2001; Li 2002; Mogk and Keir 2003; O'Driscoll et al. 1992; Pryce 1980). Related to this, Hoffman, Reed, and Chaffin (2007) observed the biomechanics of whole-body posture to dictate the direction and effective magnitude of grip force. A 3D analysis of body motion during pushing and pulling of a handle showed that adjustment of foot and pelvic positions were important to maintaining balance and generating suitable forces at the handle. Other studies have reported that deviation of arm posture from a neutral position (i.e. 90° of elbow flexion) caused reduction in the maximum grip force (Doheny et al. 2008; Kattel et al. 1996). Other research has also found that grip strength is dependent upon forearm muscle activity, including flexor digitorum superficialis (FDS) and extensor digitorum (ED) levels (e.g. Doheny et al. 2008; Hoozemans and van Dieen 2005; Radwin, Armstrong, and Chaffin 1987; Sudhakar et al. 1988). In addition, muscle activity has been found to be dependent on posture. For example, elbow and shoulder (upper extremity) position was found to influence triceps muscle activation and fatigue (Doheny et al. 2008; Kattel et al. 1996). Deviations from neutral posture lead to higher triceps activity and fatigue potential. These findings suggest that awkward body posture may reduce muscle activation potential and, consequently, grip force. These relationships of grip force/strength with arm muscle activation and upper-extremity posture are relevant to investigation of the influence of plow handle design and whole-body posture on farmer performance and potential for MSDs.

Several ergonomics studies have been conducted on the relationship of worker discomfort and awkward postures. Measurements have been collected on whole body and body part discomfort (BPD) in different work environments (e.g. Corlett and Bishop 1976; Kyung, Nussbaum, and Babski-Reeves 2008). Subjective discomfort rating scales have been used in many cases, for example rating of right-hand discomfort to identify a threshold limit in repetitive assembly work (O'Sullivan and Clancy 2007); upper-extremity discomfort in transferring and screw-driving tasks (Krawczyk, Armstrong, and Snook 1993); and whole body and BPD of driver seats (Kyung and Nussbaum 2010; Kyung, Nussbaum, and Babski-Reeves 2008). In general, the use of subjective measures is common in associating worker pain with task design.

2. Study objectives and hypotheses

Based on above literature review, we hypothesised that awkward postures of the upper extremity and whole-body asymmetry during rice field plowing tasks degrade farmer performance in plowing tasks and represent potential risk factors for MSDs. We proposed a new design of vertical plow handle to promote neutral wrist posture of farmers. This new design was compared with conventional horizontal handle design under both symmetrical and asymmetrical whole-body postures induced by level and uneven ground conditions in a simulated plowing task. We investigated the influence of the plow handle design variations as well as farmer dynamic whole-body posture position on grip force and arm muscle activity.

In general, we expected the vertical handle design to facilitate more effective use of muscles during simulated plowing (Hypothesis 1 [H1]) largely due to the associated wrist and upper-extremity posture. In specific, the measure of muscle efficiency (grip force/muscle activity) was expected to be greater when using vertical handles (with a neutral wrist posture) versus horizontal handles (H1.1). Based on the literature review, any deviations of the wrist from a neutral posture might lead to reductions in individual finger forces exerted on objects while requiring greater (or comparable) forearm muscle use (e.g. Mogk and Keir 2003; Roman-Liu and Tokarski 2002). Previous studies (e.g. Edwards 1983) have found an increase in EMG/force ratio (i.e. a decrease in force/EMG) to be associated with fatigue. Lower forearm muscle efficiency (grip force/EMG) might provide some information regarding the onset of fatigue in intervention use. Triceps muscle activity was also expected to be greater when using the vertical handles and result in lower forearm muscle activity, as compared with the horizontal handles (H1.2). Prior research suggested that vertical handles would promote use of larger muscle groups and reduce fatigue from small muscle work (Baidya and Stevenson 1988). Moreover, Vertical handles were expected to decrease whole body discomfort and subjective ratings of hand and wrist discomfort (H1.3), as a result of the neutral wrist posture position.

In general, asymmetrical whole-body posture was expected to decrease the effectiveness of muscle use, through biomechanical compensation at the upper extremities (H2). Specifically, the muscle use efficiency measure was expected to decrease when performing tasks on uneven versus even ground (H2.1). The associated deviation of the upper-extremity joints from neutral positions was expected to reduce the maximum grip force (Doheny et al. 2008; Kattel et al. 1996; Roman-Liu and Tokarski 2002) and increase forearm muscle activity (Roman-Liu and Tokarski 2002). Asymmetrical posture was also expected to increase triceps and forearm muscle activity levels as a result of farmers attempting to maintain the handles in a level position during plowing and the laser pointer projection on the target (H2.2). This activity required triceps use to stabilise the forearm during plow handle gripping (Lee, Jung, and Hwangbo 2011).

3. Material and methods

This study included a simulated plowing task performed by experienced rice farmers. Plow handle design was altered from a conventional horizontal to proposed vertical position. Participant whole-body posture was manipulated by using even and uneven simulated ground type. The experiment was conducted in the Physical Therapy Laboratory at Khon Kaen University. The study was approved by the Khon Kaen University Ethics Committee of Human Research (HE 542141).

3.1 Participants

A total of 24 male farmers were recruited from large rice farms in the Khon Kaen, Thailand area. This study investigated only male farmers because the vast majority of Thai farmers performing plowing tasks are male. All participants were 18 years or older. Participants were also required to have at least two years of experience in rice patty plowing. Participants were excluded from the study if they had: (1) an open or chronic wound of the upper extremity; (2) an accident causing a fracture or dislocation of an upper extremity; or (3) fever, chill or dizziness on the day of the experiment.

3.2 Apparatus, task and experimental conditions

A simulated rice plowing machine was constructed using a patient lift-assist device equipped with two types of plow handles: horizontal and vertical handles (bent downward 13° and 50° from horizontal, respectively; see Figure 1C–D). For data collection, a grip force sensor (Biopac Systems, Co.) was attached to the right handle of each handle type. A 20-kilogram load was attached to the front of the handles in order to simulate the weight of a plow motor. This weight was determined by using force sensors to measure forces at the handles of a real plow machine. The weight was also subjectively verified by two experienced farmers based on the use of a powered tiller. Custom-made terrain (length of 10 m) was used to simulate even and uneven ground (a height difference of 17 cm; average measurement based on multiple field observations of furrow vs. level ground) conditions common in plowing tasks (see Figure 1A–B). Rumble strips were also attached to the simulated terrain, running beneath wheels of the plowing apparatus, in order to replicate vibration of a real plowing machine.

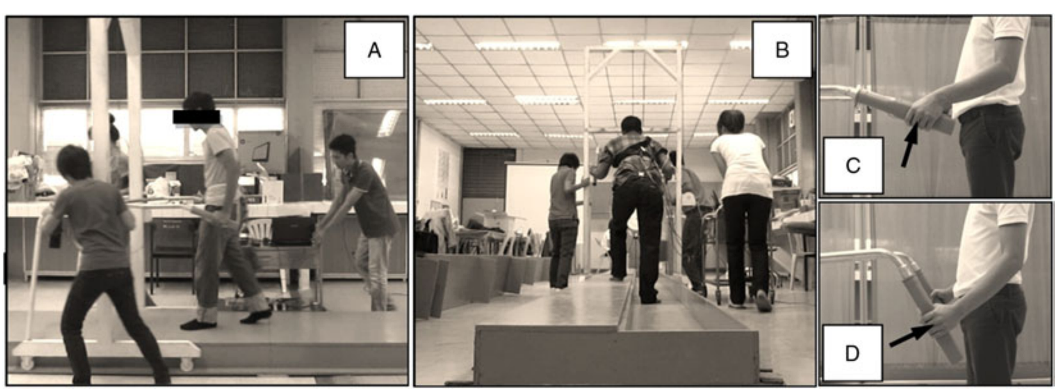

Figure 1. Simulated plowing machine and handle designs: (A) side view of a participant using ‘ horizontal’ handles on even ground; (B) posterior view of a participant using vertical handles on uneven ground; (C) conventional horizontal handle design; and (D) proposed vertical handle design.
Note: Arrows in C and D represent reaction force from handle.

Each subject was asked to walk on even and uneven 'ground' while pushing the simulated tiller using the different handle types. A laser pointer was mounted on the tip of handles and participants were required to maintain the projected point in a target area at the end of the simulated terrain. This approach was used to promote accurate participant control of the machine; however, performance in the simulated machine control was not analysed. Based on the combinations of handle type and terrain configuration, four experimental conditions were presented to each participant, including: (1) horizontal handle with even terrain (HE); (2) horizontal handle with uneven terrain (HU); (3) vertical handle with even terrain (VE); and (4) vertical handle with uneven terrain (VU).

3.3 Response measures

Electromyography (EMG) was performed on the right FDS, ED and triceps brachii muscles to quantify activity levels of the right-arm muscles during simulated plowing. The skin over the anatomical locations of these muscles was prepared for electrode attachment by shaving hair, cleaning sites with alcohol and abrading the skin surface using fine sandpaper. These steps were iterated, if necessary, to reduce skin impedance to less than 10 kΩ (Hermens et al. 2000). Three pairs of active adhesive disposable Ag/AgCl disc surface electrodes (EL 503,BIOPAC Systems, California) were then placed on each muscles. EMG electrode placement followed the guidelines from Basmajian and Blumenstein (1989). A Biopac MP 36 sEMG system (Goleta, California) was used to continuously record EMG signals during the plowing trial. Signal sampling rate and post-process methodology followed the procedure previously used to eliminate electrical system interference in Thailand (e.g. Eungpinichpong et al. 2013). The rectified EMG signals were normalised based on the maximum EMG response during test trials.

Grip force was also recorded on right hand during test trials using the BiopacMP 36 system linear force sensor mounted in the handles of the simulated plowing apparatus. The sensor was set to record forces, exerted by the fingers against the handle, at 60 Hz. All grip force data were normalised based on individual maximum grip force observed during experiment trials.

Previous studies demonstrated the ratio of grip force to forearm EMG to be an indicator of efficiency of muscle used in gripping tasks (Ashton 1984; Ayoub and Presti 1971). Consequently, the ratio of grip force to EMG (grip force/EMG) was computed for the FDS and ED muscles. Triceps muscle efficiency was not analysed as the muscle is not a prime mover in gripping tasks.

We also assessed farmer discomfort in this study by using a subjective rating scale. In specific, the whole-body discomfort rating (WDR) and upper BPD rating scales were used to identify discomfort levels at the end of each of the plowing trials. Visual analog scales were used for WDR (Kyung, Nussbaum, and Babski-Reeves 2008). Participants were asked to draw a vertical mark on a 100- mm line at the location that indicated their level of discomfort from 0, or 'no discomfort', to 100, or the 'most discomfort possible'. Participants were also asked to rate their discomfort level for each body part using BPD from Corlett and Bishop (1976). Body regions included the neck, left and right shoulders, arms, forearms and hands. The rating scale that was applied ranged from 0, or 'no discomfort', to 10, or 'extremely strong discomfort' (Kyung, Nussbaum, and Babski-Reeves 2008). To address individual differences in internal scaling of discomfort, the subjective responses were normalised for each participant in terms of z-score.

3.4 Procedures and experiment design

At the beginning of the experiment, participants were provided with an explanation of the study, including the purpose, protocol and benefits. They signed an informed consent form and completed a demographic questionnaire, including age, weight, height and plowing experience time**.** They were subsequently trained in the simulated plowing task on the simulated terrain. This was followed by training with the physiological response measurement equipment attached to body. Following this, participants completed two sets of trial under all handle × terrain configuration conditions (i.e. HE, HU, VE and VU).

Table 1. Participant characteristics.

Characteristics	Mean (SD)
Age (year)	35.92 (11.29)
Body weight (kg)	63.40 (10.78)
Height (cm)	166.17 (6.86)
Body mass index (kg.m^{-2})	26.91 (19.85)
Plowing experience (year)	14.25 (9.75)

Each participant was instructed to maintain the laser pointer projection in the target area at the end of the terrain, while two researchers pushed the machine at a pace of 0.4 $m.s^{-1}$ according to a metronome and stride length markers on the terrain surface. Each plowing trial lasted for about 30 seconds and participants rested for 2 minutes between trials.

The experiment followed a Latin Square design balanced for trial carryover effects among conditions and with replication. Replication of squares was used to assess within-subject variability for all test conditions.

4. Analyses and results

All 24 male farmers recruited for the study completed experiment trials. There were no absences or attrition. Participants ranged in age from 21 to 55 years and had experience in rice field plowing between 2 and 40 years. Study sample demographics are summarised in Table 1.

The descriptive statistics for each response measure under each experimental condition are presented in Table 2. In general, the proposed vertical handle design increased efficiency in forearm muscle use (i.e. the ratio of grip force to muscle activity; approximately 14% for the FDS across even and uneven ground; 5.25% and 0.5% for the ED for even and uneven ground, respectively). The vertical handle design also promoted triceps muscle activity (54.76% increase for even ground and 61.82% increase for uneven ground). When compared with the same handle type, asymmetry in whole-body posture decreased efficiency of forearm muscle use (approximately 2% for the FDS for both handle designs; 2.6% and 7% increase for ED efficiency for horizontal and vertical handles, respectively) and increased triceps muscle activity (5% increase for horizontal and 9.8% increase for vertical designs).

An analysis of variance on the EMG response measures revealed a significant treatment effect for the ED ($F(3,132) = 4.18$; $p = 0.007$) and triceps ($F(3,132) = 49.39$; $p < 0.0001$); however, there was no significant effect for the FDS. The Latin Square design was effective for controlling variation due to nuisance variables; therefore, no significant trial order and individual difference effects were observed for the EMG responses. Tukey's post-hoc analysis indicated significantly greater ED activity occurred with the vertical handles on uneven surfaces (Figure 2A), as compared with either horizontal either use (HE, HU).In addition, post-hoc results indicated significant differences in triceps activity due to the handle design (Figure 2B) with the vertical handles producing greater activity than horizontal. However, there were no differences in triceps activity due to terrain.

Results on the grip force response revealed significant treatment effects ($F(3,129) = 2.75$; $p = 0.045$). There was a trend for greater grip forces with the vertical handles and when farmers walked on uneven ground. Tukey's post-hoc analysis indicated that grip force was greatest in vertical handle use on uneven ground as compared to horizontal handle use on even ground. It is possible that farmers were able to generate greater grip forces when using the vertical handles and the uneven ground likely dictated the need for greater forces to maintain plow control. All other conditions were statistically comparable (see Figure 3).

Significant effects of handle design and posture position were observed for FDS muscle efficiency ($F(3,129) = 2.81$; $p = 0.042$), while no significant treatment effect was found for ED muscle efficiency. Results (see Figure 4) indicated that the ratio of grip force to FDS activity in using vertical handles under even ground conditions was significantly greater than using horizontal handles on uneven ground. There was no significant difference in the use of horizontal handles when plowing on an even surface and vertical handle use on even or uneven surfaces.

Table 3 summarises the statistical test results on the WDR and BPD ratings. A significant treatment effect was found for WDR. Analyses of the subjective discomfort ratings also revealed significant treatment effects for ratings for several body parts, including the neck, left upper arm, right upper arm, left forearm and left hand. In general, farmers rated greater discomfort when using vertical handles. Post-hoc analysis on the interaction of handle design and ground configuration revealed discomfort for the upper extremities to be greater with vertical handles under uneven ground conditions than horizontal handle use on even ground. Participants rated discomfort for HU and VE as similar.

Table 2. Descriptive statistics on response measures under each experimental condition (numbers in parentheses are SD).

Conditions	Grip (kg)	FDS (mV)	ED (mV)	Triceps (mV)	FDS Efficiency ($kg.mV^{-1}$)	FDS Efficiency ($kg.mV^{-1}$)
HE	0.45 (0.03)	0.27 (0.02)	0.21 (0.01)	0.17 (0.01)	1.88 (0.11)	2.22 (0.11)
HU	0.48 (0.03)	0.28 (0.02)	0.23 (0.01)	0.18 (0.01)	1.85 (0.11)	2.16 (0.10)
VE	0.52 (0.02)	0.26 (0.02)	0.24 (0.01)	0.26 (0.01)	2.16 (0.11)	2.34 (0.11)
VU	0.54 (0.02)	0.28 (0.02)	0.27 (0.01)	0.28 (0.01)	2.12 (0.12)	2.17 (0.13)

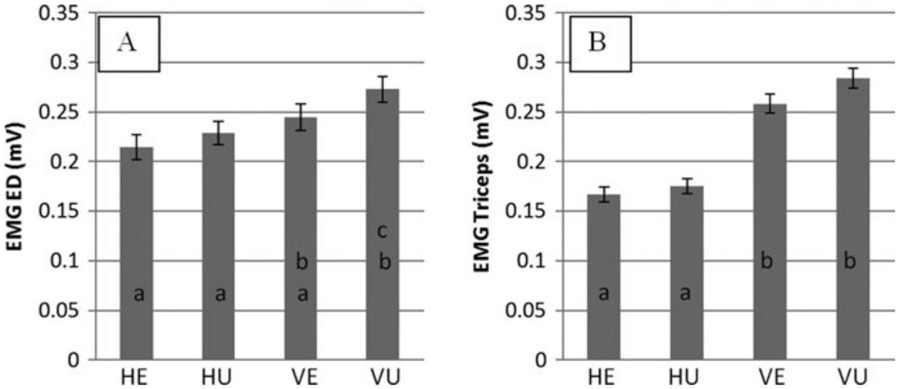

Figure 2. Post-hoc results on EMG activity of: (A) ED muscle and (B) triceps muscle. Means with different letter labels are significantly different from the each other at $\alpha = 0.05$.

5. Discussion

Inline with our hypothesis (H1), results generally demonstrated more effective muscle use with the proposed plow handle design. In specific, the vertical handle design significantly increased efficiency in FDS muscle use. Forces generated at hands with vertical handles were greater for comparable levels of muscle activation with horizontal handles. A number of previous study reported that wrist work near a neutral posture yielded greater grip force than other posture positions (Fong and Ng 2001; Li 2002; O'Driscoll et al. 1992; Pryce 1980). However, no significant difference was found in ED muscle efficiency. Although the vertical handles helped generate greater grip force, they failed to provide an advantage in terms of effectiveness of ED muscle use. This result might have been due to the ED acting as a synergistic muscle in the gripping task versus serving as a prime mover, like the FDS. The ED muscle counter-balanced forces generated at the fingers and wrist during power griping. Consequently, when power grip force increased, the activity level of the ED muscle also increased (Mogk and Keir 2003).

In line with expectation (H1.2), results also indicated that triceps activity increased when using the vertical handles. The neural wrist posture associated with the vertical handle design promoted the use of the larger upper-arm muscle for forearm stability of the forearm in the gripping task (Baidya and Stevenson 1988).

Contrary to hypothesis (H1.3), participants rated WDR and discomfort of the hand to be higher when using the vertical plow handles. These ratings might be attributable to farmers being accustomed to conventional horizontal handle design. The discomfort ratings also indicated that farmers were unaware of, or insensitive to, small forearm muscle fatigue. Fatigue of the ED and FDS in strenuous work tasks may increase the occurrence of awkward wrist postures when using horizontal handles and increased carpal tunnel compression. That is, the lack of farmer awareness may contribute to greater disease states.

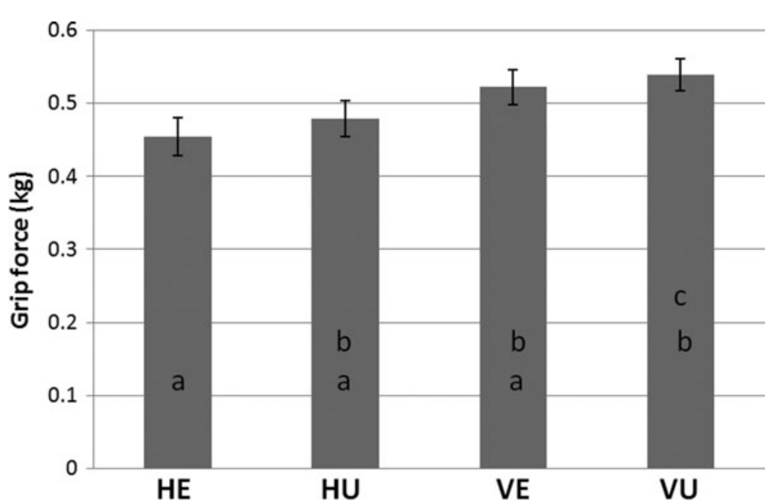

Figure 3. Post-hoc results on grip force. Means with different letter labels are significantly different from the each other at $\alpha = 0.05$.

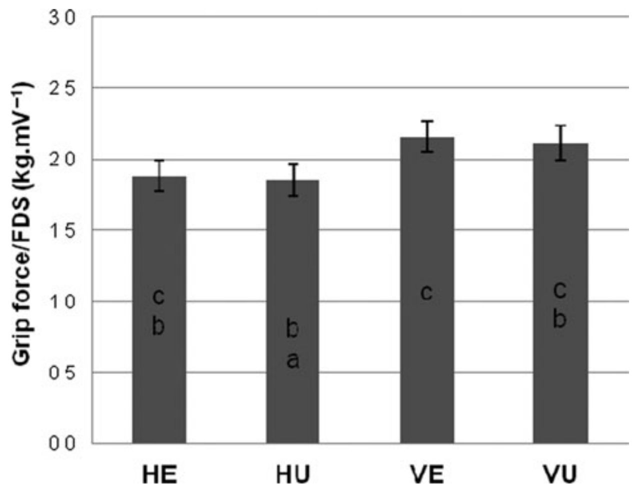

Figure 4. Post-hoc results on FDS muscle efficiency. Means with different letter labels are significantly different from the each other at $\alpha = 0.05$.

Table 3. Results on WDR and BPD ratings.

Body part	Num DF	Den DF	*F*-value	*p*-value
Whole body	3	124	6.66	0.0003[a]*
Neck	3	68	4.87	0.0040[a]*
Shoulder				
Rt.	3	100	0.84	0.4742
Lt.	3	100	1.66	0.1806
Arm				
Rt.	3	92	7.37	0.0002[a]*
Lt.	3	108	8.59	<.0001[a]*
Forearm				
Rt.	3	84	2.63	0.0556
Lt.	3	100	3.21	0.0262[a]*
Hand				
Rt.	3	73	2.72	0.0508
Lt.	3	84	4.19	0.0081[a]*

*[a]Indicates a significant difference at the $\alpha = 0.05$ level.

In line with H2.1, whole-body posture asymmetry decreased efficiency in FDS muscle use for both types of handles. Referring to Ayoub and Presti's (1971) approach, in specific, the average grip force under the HU condition was 1.85 times the corresponding FDS activity, which was significantly lower than the average grip force under the VE condition (2.16 times the corresponding FDS activity). Please note that the HU condition, in which participants generated the lowest muscle efficiency, represented the current situation of rice plowing activity in Thailand. The results on the influence of whole-body posture on efficiency in muscle use also showed that when the ground was even and posture was basically symmetrical, the use of horizontal handles was as good as vertical handles. In general, an even work surface promoted the effectiveness of muscle use with both types of handles.

In partial support of H2.2, postural asymmetry appeared to have the greatest influence on ED activity when farmers used the vertical plow handles. Vertical handles promote a neutral wrist posture and allow for greater gripping force under challenging terrain conditions. We observed farmer use of the extensors to prevent bending at the wrist with strong handle gripping under uneven terrain conditions. Contrary to our expectation (H2.2), results on triceps activity showed no significant differences under different terrain conditions. From a post-experiment video recording review, we observed that farmers adjusted their body posture in response to the uneven terrain by raising their right arm to balance the load of the plowing apparatus across their arms. This postural adjustment might have accounted for any differences in upper-arm muscle activation that would have been observed otherwise. Here, it is important to note that the simulated terrain in the lab did not include natural materials (e.g. dirt, mud) and the uneven terrain condition was consistent in the difference in the level of one foot relative to the other at ground. In a real rice field, the ground surface level may vary and interact dynamically with body posture when farmers work with power tillers. Such undulating terrain may produce varying biomechanical effects, such as changes in triceps activity levels.

By excluding previously injured farmers, the current scope of this study did not include analysis of treatment effects on secondary prevention (i.e. post-injury). Therefore, the results are only applicable to an uninjured farmer population. The intervention could potentially be ineffective in the disorder pathway as a secondary prevention, if participants discomfort was not due to unaccustomed use.

Besides this, there are some limitations of this study. First, the study did not investigate direct muscle fatigue outcomes. The study attempted to relate the effects of handle design intervention and body posture condition on the reduction of fatigue potential and health effects through investigation of force, muscle efficiency and use of larger versus smaller muscle groups. Future research should examine muscle fatigue as it may be a potential indicator of MSDs. Another limitation of the study included no measurement of other potential response measures. Wrist and body posture might also pose affects on elbow and shoulder loads (Roman-Liu and Tokarski 2002). Asymmetry of body posture might be relevant to abdominal and erector spinae muscle force (Vink et al. 1992). Such posture might also influence lower back discomfort.

6. Conclusions

The purpose of the present study was to investigate the influence of rice plow handle design as well as farmer whole-body posture position on efficiency in muscle use and subjective discomfort ratings in simulated plowing tasks. The experiment presented a simulation of rice field terrain and the use of a powered tiller in a plowing task. Findings indicated efficiency to be highest with a proposed vertical handle design under optimal (even) terrain conditions. The lowest muscle efficiency was found when farmers used conventional horizontal handles on uneven ground. These findings indicate that changes in either the farmer's tool design, promoting a neutral wrist posture, or their work environment, facilitating symmetrical body posture, could help increase the effectiveness of muscle use by as much as 30% and reduce the potential for MSDs in rice cultivation operations.

With respect to the change in tool design, vertical handle design should be used for power tillers in order to promote neutral wrist posture and reduce potential compression forces in the carpal tunnel. The proposed design also promotes large upper-arm muscle use for greater plow control and prevention of small forearm muscle fatigue. Finally, the design promotes efficiency in muscle use for grip force at plow handles and may reduce upper-extremity fatigue and potential for injury.

It is also important to consider ergonomic interventions to eliminate asymmetrical whole-body posture in the rice plowing activity. For example, special footwear designs should be considered to address unequal leg lengths and reduce foot eversion when walking in furrows. In addition, the integration of hinge joints in the handles of a power tiller could be used to allow for asymmetrical positioning of handles to prevent awkward whole-body posture, when farmers use tillers on uneven ground.

A long-term field test on the use of the proposed handle design by farmers is also needed to evaluate the long-term influence on plowing behaviour, effectiveness for work and perceived comfort. Findings on farmer subjective ratings of discomfort indicated that they were unaware of small forearm muscle fatigue and potential carpal tunnel compression due to awkward wrist posture when using horizontal handles. Such findings can be used to direct education of farmers on the potential for hand and arm injury due to muscle fatigue as well as risky working postures.

Finally, future study needs to investigate direct muscle fatigue outcomes and other potential response measures associated with wrist and body posture, including elbow, shoulder and back muscle loading and activity. Future research should also include injured farmers in order to examine the intervention as a form of secondary prevention. More realistic rice field terrain conditions should be included in the study in order to further assess the effects of dynamic postural asymmetry on experienced farmer muscle activation levels and grip forces in plowing tasks. In addition, other rice cultivation operations (besides plowing) need to be investigated for potential ergonomics-related risks. Such investigations may provide a further basis for educating farmers on the potential for MSDs in rice cultivation and for developing guidelines to promote safe cultivation practices in consideration of expected increases in Thai rice production.

Acknowledgements

This study was supported by a grant from National Research Council of Thailand (NRCT) (No. 560026). David Kaber's work on the study was supported by a grant from the US National Institute for Occupational Safety & Health (NIOSH) (No. 2 T42 OH008673-06). The opinions expressed in this paper are those of the authors and do not necessarily reflect the views of NRCT and NIOSH.

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