International Journal of Industrial Ergonomics 110 (2025) 103819

Contents lists available at ScienceDirect

International Journal of Industrial Ergonomics

journal homepage: www.elsevier.com/locate/ergon

The effectiveness of an ergonomics programme to reduce musculoskeletal disorders in high voltage overhead powerline workers

Sunisa Chaiklieng [a,*], Apiwat Youngwilai [b], Mark G. Boocock [c]

[a] Department of Occupational Safety and Environmental Health, Faculty of Public Health, Khon Kaen University, Khon Kaen, Thailand
[b] Provincial Electricity Authority, Map Tha Phut, Rayong, Thailand
[c] Ergonomics and Human Factors Group, Auckland University of Technology, New Zealand

ARTICLE INFO

Keywords:
Ergonomic interventions
Musculoskeletal disorders
Powerline workers
Risk factors

ABSTRACT

High voltage overhead powerline work is physically demanding and exposes workers to a high risk of work-related musculoskeletal disorders (WRMSDs). This study investigated the effectiveness of interventions to reduce the risk of WRMSDs in powerline operators. Sixteen operators from Thailand who regularly used mobile elevating work platforms participated in the study. Following a task evaluation, an ergonomics improvement programme was implemented which involved engineering-design changes (e.g. purpose designed handling devices) and ergonomics training (e.g. techniques to reduce physically demanding postures). Pre- and post-intervention measures involved a musculoskeletal health survey, Rapid Entire Body Assessment (REBA) and the assessment of WRMSD risk levels (risk matrix). The ergonomics improvement programme led to changes in postures and working practices, and a reduction in WRMSD symptom reporting and WRMSD risk classifications when compared to pre-intervention measures. Following the intervention, musculoskeletal discomfort decreased by 25 % in the hands and wrists, 12.5 % in the shoulders, arms, and lower back, and 6.3 % in the neck, upper back, hips, knees, feet, and ankles. There was a significant shift to lower REBA scores and risk matrix classifications changed from high to medium risk. The implementation of engineering-designed changes combined with ergonomics training was effective in reducing the short-term risks associated with WRMSDs in high voltage overhead powerline workers. Further work is needed to determine the long-term effects of these interventions on the occupational health of powerline workers, along with strategies for addressing other risk factors (e.g. psychosocial, work organisation) known to impact on the incidence of WRMSDs.

1. Introduction

The recent economic climate in Thailand has led to a rapid expansion in businesses and industrial premises, resulting in an increased demand for electricity. Between 2015 and 2018, industries and other businesses in Thailand consumed approximately 61 % of the total electricity consumption (Energy Policy and Planning Office, 2020). Consequentially, the demands placed on organisations responsible for maintaining and managing electrical power networks has increased, adding to the number of employees in the profession and their workloads.

High voltage overhead powerline workers involved in the installation and maintenance of electricity networks have been shown to be at a high risk of work-related injuries (Volberg et al., 2017). A review of injury data (recordable injuries and medical claims) from electrical utility companies across the USA over an 18-year period (1995–2013) identified powerline workers had an injury rate of 10.4 per 100 employee-years (Volberg et al., 2017), the third highest job type behind welders and meter readers. Among powerline workers, the most frequently reported injuries are work-related musculoskeletal disorders (WRMSDs) (Kelsh et al., 2004; Padmanathan et al., 2016). A survey of thirty Brazilian powerline employees found that during the previous 12 months, 87 % of workers experienced at least one musculoskeletal symptom in the shoulders (43 %), back (43 %) or knees (30 %) (Moriguchi et al., 2009). In the USA, neck injuries were found to be common amongst powerline workers, with an injury rate of 31.8 per 10, 000 employee-years (Fordyce et al., 2010).

The costs associated with WRMSDs in electrical workers are considered high due to the number of lost workdays, reduced productivity, high medical costs, and costs associated with staff replacement and retraining (Seeley and Marklin, 2003; Padmanathan et al., 2016).

* Corresponding author. Ergonomics and Human Factors Group, Auckland University of Technology, New Zealand.
E-mail addresses: csunis@kku.ac.th (S. Chaiklieng), mark.boocock@aut.ac.nz (M.G. Boocock).

https://doi.org/10.1016/j.ergon.2025.103819
Received 14 May 2025; Received in revised form 10 September 2025; Accepted 29 September 2025
Available online 8 October 2025

According to Fordyce et al. (2016), powerline workers in the USA had one of the highest severe injury rates when measured by lost workdays, accounting for the largest share (28 %) of medical costs within the electrical distribution sector.

Overhead powerline workers are at significant risk of WRMSDs due to the potentially hazardous and unpredictable nature of the work and the work environment. They often face additional challenges from the stressful conditions under which they normally work, e.g. emergency or time-pressured situations (Kelsh et al., 2004; Päivinen, 2006; Padmanathan et al., 2016). The work is often physically demanding and can involve long shifts. Tasks considered to expose powerline workers to a high risk of WRMSDs are the manual handling of tools and the high hand forces associated with the use of heavy and awkward to handle equipment, such as crimping tools and wrenches (Graves et al., 1996; Parkhouse and Gall, 2004; Padmanathan et al., 2016). Much of the work involves the installation of overhead bars or insulators, often while working inside mobile elevating work platforms (MEWPs) that restrict movements and leads to awkward, twisted and sustained trunk and neck postures, often with the arms and hands above shoulder height (Kelsh et al., 2004; Yu et al., 2009; Moriguchi et al., 2013; Gemma et al., 2019).

To understand the risks associated with WRMSDs in overhead powerline operators, several authors (Moriguchi et al., 2009; Fordyce et al., 2016; Padmanathan et al., 2016) identify the need for detailed job analysis to inform interventions. There is also a dearth of information relating to the physical, psychosocial, environmental and organisational risk factors associated with this type of work, inhibiting targeted interventions. Although some studies have shown a significant return on investment from implementing simple ergonomic modifications, such as power tools (Seeley and Marklin, 2003), further insights into the effectiveness and cost-benefits of multifaceted interventions are needed (Moriguchi et al., 2009; Padmanathan et al., 2016). The aim of this study was to identify hazardous work tasks performed by high voltage overhead powerline workers in Thailand, and develop, implement and evaluate interventions to reduce the risk of WRMSDs in these workers.

2. Materials and methods

2.1. Study design and participants

A pre-post intervention study was undertaken involving a convenience sample of overhead powerline workers from the Provincial Electricity Authority in Rayong Province of Thailand. Sixteen male workers aged 19–38 years volunteered to participate in the study. To be included in the study participants were required to have a minimum of one year's work experience (range = 1–19 years), their work should primarily involve the installation and maintenance of high voltage overhead powerlines, and they should use MEWPs to carry out their work. Participants were excluded if they had: a cardiovascular or neurological condition; experienced a musculoskeletal injury within the last six months leading to time off work; or undergone previous musculoskeletal surgery.

The study was conducted over a 3-month period (Fig. 1), divided into an initial data collection phase (Month 1), intervention phase (Month 2) and post-intervention evaluation phase (Month 3). The project was approved by the Khon Kaen University Ethics Committee for Human Research (project number HE633078).

2.2. Questionnaire survey

At the initiation of the study (Week 1), each participant completed a questionnaire detailing personal demographics and potential WRMSDs. Demographics included information on the age of the participant, job roles, work experience, and accidents/injuries experienced at work over the past year. This was supplemented with information on work organisation and work practices taken from company records. The musculoskeletal questionnaire was a modified version of the Nordic musculoskeletal questionnaire (Kuorinka et al., 1987) translated into Thai (Chaiklieng et al., 2010). It sought information on self-reported musculoskeletal complaints (e.g. discomfort, pain) experienced during the previous 7 days and during the last month. The modified version included additional questions relating to the severity and frequency of symptoms, as reported elsewhere (Homsombat and Chaiklieng, 2017). The questionnaire has been used extensively across a range of industries and service sectors in Thailand (Chaiklieng et al., 2016; Chaiklieng, 2019; Poochada and Chailklieng, 2022) and shown to have good reliability (Homsombat and Chaiklieng, 2017).

Musculoskeletal complaints were defined as "aches, pain, or discomfort that have been caused by your work". Those identifying a musculoskeletal complaint were asked to identify the body region affected (ten body parts: neck, shoulders, upper back, lower back, arms, hands/wrists, hips, knees, legs and feet/ankles) and rate the frequency and severity of symptoms. The frequency of symptoms for the previous 7 days and during the last month was rated by participants according to a five-point scale that assigned a score of 0–4: no symptoms (score = 0); 1–2 times per week (score = 1); 3–4 times per week (score = 2); daily (score = 3); and several times every day/persisting for 24 h or more (score = 4). The severity of symptoms was also rated according to a five-point scale (scored between 0 and 4): no discomfort (score = 0); mild discomfort (annoying, minimal interface to work) (score = 1); moderate discomfort (pain, sometimes interferes with work) (score = 2); severe

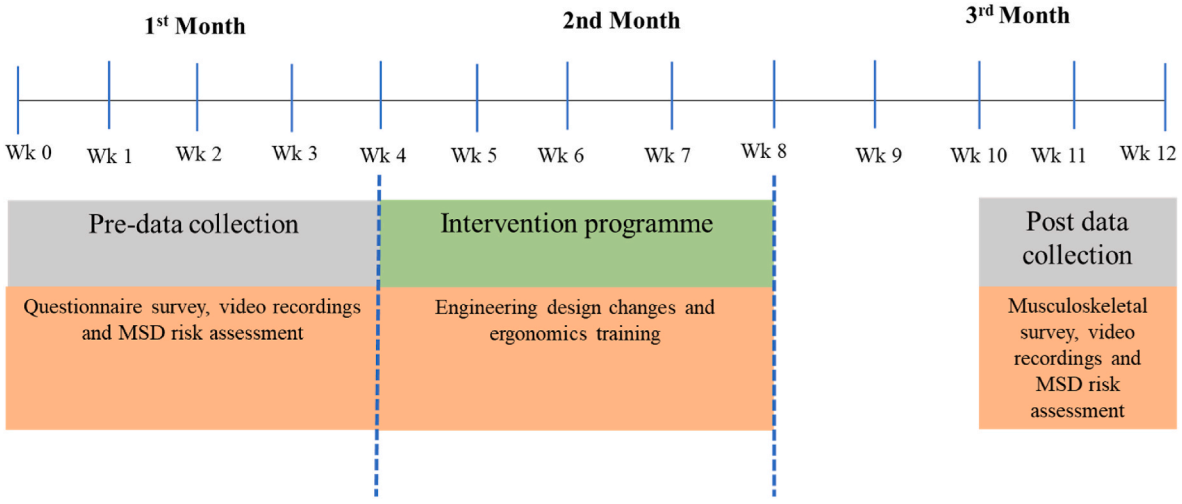

Fig. 1. The study timeframe showing the data collection time points and when interventions were implemented.

discomfort (persistent pain that prevents work) (score = 3); and very severe discomfort (persistent pain that prevents work and impacts on activities outside work) (score = 4).

The frequency and severity of complaints for each body region were multiplied to obtain an overall WRMSD rating score (Chaiklieng, 2019), resulting in a five-point classification of symptoms: non (scores = 0), mild (scores ranging between 1 and 2), moderate (scores ranging between 3 and 4), severe (scores ranging between 5 and 8), and very severe (scores >8). The survey of WRMSDs was repeated at the end of the study (Month 3, Week 4).

2.3. Identification of work tasks

A detailed task analysis was conducted of participants disconnecting, maintaining, and reconnecting high voltage overhead powerlines, a standard and frequently performed task. The job was broken down into three main tasks, comprising several sub-tasks. The three primary tasks were:

- Task 1. *Preparation*: which included the laying out of traffic cones to cordon off the work area and the installation of a ground wire to ensure electrical safety of the operators. Operators were also required to don personal protective equipment (e.g., harnesses, high visibility jackets) and select, handle and install equipment necessary for the job (e.g. earthing rod).
- Task 2. *Line working*: which involved operators disconnecting and reconnecting the overhead powerlines using the MEWP to access the powerline. Sub-tasks involved the use of manually operated hand wrenches to loosen and tighten cable joints and the manual handling of electrical cables.
- Task 3. *Disassembly*: which involved a reversal of the preparation phase, i.e., the removal of the ground wire and traffic cones, returning equipment to the vehicle, and taking off and storing personal protective equipment.

2.4. WRMSD risk assessment

Based on the task analysis and observations of workers performing the three main tasks (preparation, line working, and disassembly), five tasks were considered to present a risk of musculoskeletal injury. These were: 1) cordoning off the work area using traffic cones (preparation phase); 2) installing the ground wires (preparation phase); 3) the disconnecting and reconnecting of overhead powerline cables (line working); 4) the disconnecting of the ground wire (disassembly phase); and 5) the collecting of traffic cones from the cordoned off area (disassembly phase). Video recordings, sometimes using drones to capture workers in the MEWP, were taken of workers performing each of the three main tasks. Where possible, the hand-held digital camera and drone were positioned in such a way as to record images of the workers in the frontal and sagittal planes. These recordings were reviewed to identify the start and end of each sub-task, e.g. picking up of traffic cones from the vehicle and transporting to their selected location. A minimum of five selected postures for each sub-task were analysed using the Rapid Entire Body Assessment (REBA) method (Hignett and McAtamney, 2000). The posture resulting in the highest risk score was used to rate each sub-task. These postures were selected following discussions with engineers, supervisors and workers, along with input from the occupational health and safety practitioner who had training in ergonomics. The REBA analysis was conducted by the occupational health and safety practitioner. REBA was considered the most appropriate tool to use when assessing the range of work tasks, as most tasks involved full body activities, not always with high force exertions. In line with Hignett and McAtamney (2000) risk classification, REBA scores were rated as: negligible risk (score = 1); low risk (score = 2 or 3); moderate risk (score = 4 to 7); and high risk (score = 8 to 10).

A risk matrix was used to evaluate the likelihood of WRMSDs, which was derived according to the WRMSD discomfort rating and REBA score (Table 1) (Chaiklieng, 2019). Each participant was assessed according to the body part experiencing the most discomfort and assigned an WRMSD risk rating of: 'acceptable risk' (0; green), 'low risk' (1–2; yellow), 'moderate risk' (3–4; light orange), 'high risk' (5–8; dark orange) and 'very high risk' (>8; red).

2.5. Ergonomic interventions

Following the assessment of work tasks and discussions with operators, a series of engineering-design changes were developed and implemented (Fig. 2), along with an ergonomics training programme. The engineering-design changes were targeted at reducing physical loads on operators and included: (1) the use of a purpose-designed trolley cart for setting out and collecting traffic cones to reduce the risks associated with manual handling (Fig. 2A); (2) an electric wrench, as opposed to a hand wrench, to reduce hand force exertions and awkward, repetitive wrist postures (Fig. 2B); and (3) a cable reel to reduce the physical exertions associated with the handling of earthing wires (Fig. 2C). The design solutions were developed through consultations with workers, safety engineers, and ergonomists.

The ergonomics training consisted of awareness of ergonomic hazards and appropriate working practices to reduce the risk of musculoskeletal injury, using an approach similar to that described by Ali and Samarasena (2019). The training programme was conducted on site with workers and lasted for approximately 30 min. A follow-up visit was conducted approximately 2 weeks after the initial training to discuss problems, provide an opportunity to ask questions, and discuss situations encountered in the field. The training was broken down into the three main tasks (preparation, line working and disassembly) and addressed basic ergonomic principles, e.g. adjusting the position of the MEWP to avoid reaching and maintaining hands at or below shoulder height. The training also incorporated information and practical, hands-on experience of using the engineering-design solutions, e.g., appropriate handling of the electric power wrench. Along with an ergonomist, the training was administered by a safety engineer who had been involved in developing the interventions. The engineer also had a detailed knowledge and understanding of the work performed by powerline operators. The intervention programme was administered over a two-week period, at the start of the second month. The musculoskeletal survey, video recordings and REBA assessment were repeated during the final two weeks of the study (Month 3, Weeks 3 and 4) (Fig. 1).

2.6. Statistical analysis

Descriptive statistics (number and percentage of workers) were derived for pre- and post-intervention REBA, WRMSD discomfort and WRMSD risk matrix classification scores. Pearson's chi-square (χ^2) test was used to determine differences in REBA and WRMSD risk matrix classification pre- and post-intervention. All statistical analysis was performed using the STATA (Version 10.1, StataCorp LLC, Texas, USA) statistical software programme. The level of significance was set at $p < 0.05$.

3. Results

3.1. WRMSD discomfort pre-/post intervention

The number of reported WRMSD complaints (previous month and last 7 days) by body region pre- and post-intervention is presented in Fig. 3. Prior to the intervention, most reports of WRMSD discomfort were for the arms (9 operators, 56.3 %), followed by the neck, and hands/wrists (8 operators, 50 %). With the exception of legs, the intervention led to a reduction in the number of operators reporting discomfort in each body region, with a 25 % reduction in hands/wrists discomfort, a 12.5 % reduction in shoulder, arm and lower back

Table 1
The WRMSD risk assessment matrix.

		REBA rating (1 to 4)			
		1	2	3	4
WRMSD discomfort rating (0 to 4)	4	4	8	12	16
	3	3	6	9	12
	2	2	4	6	8
	1	1	2	3	4
	0	0	0	1*	2*

Adapted from Chaiklieng (2019)

discomfort, and a 6.3 % reduction in neck, upper back, hip, knee, and feet/ankles discomfort (Fig. 3).

Prior to the intervention, 37.5 % of operators (n = 6) experienced moderate to very severe discomfort/pain in at least one body region, with the upper and lower back being most affected. This number decreased to 18.8 % (n = 3) following the intervention. For symptoms occurring 3–4 times per week, five workers (31.3 %) reported discomfort/pain prior to the intervention, with two reporting discomfort/pain in the upper back, two in the lower back, and one in the leg. Following the intervention, this number decreased to three (18.8 %), with two reporting discomfort/pain in the lower back and one in the leg. Across all body regions, 45 WRMSD were reported to occur 1–2 times/week, which decreased to 32 following the intervention (Table 3).

3.2. REBA assessment of work tasks pre-/post intervention

The mean (range) REBA scores for the five tasks are shown in Table 2. Prior to the intervention, all tasks were rated as high risk. Within each of the three main tasks, the highest mean scores occurred for:

- Handling traffic cones (preparation) - mean REBA score of 7 and range = 5–7, due primarily to the multiple handling of cones.
- Overhead wire installation (line working) - mean REBA score of 9 and range = 7–11, due mainly to awkward trunk (bending and twisting) and upper arm postures (extended reach while repeatedly tightening clamps).
- Handling of traffic cones (disassembly) - mean REBA score of 10 and range = 9–11, due primarily to the multiple handling of cones.

Following the interventions, mean REBA scores ranged between 4 and 7 across all tasks (medium risk) (Table 2). During preparation and disassembly, the use of the trolley cart for handling traffic cones reduced loads handled, awkward trunk postures and repetitive arm movements. Improvements were also noted for the arm postures adopted when loosening the ground wire during the cable reel task. During line working, the use of the powered wrench when tightening clamps resulted in improvements in hand/arm postures and hand coupling. Appropriate positioning of the MEWP, as emphasized during training, was also considered an influential factor in affecting work posture and the subsequent REBA scores. Differences in REBA scores pre- and post-intervention were significant ($p < 0.01$).

3.3. WRMSD risk matrix

There was a shift to lower levels of WRMSD risk (risk matrix rating) following the intervention. The intervention resulted in the mean WRMSD risk rating decreasing from 3.51 (level 4: high risk) to 2.94 (level 2: medium risk). Prior to the intervention, five operators had a WRMSD risk rating of high to very high. This dropped to 3 workers following the intervention (Fig. 4). There was an overall reduction in those workers classified as medium to high risk, with 3 additional workers (5 in total) considered to be at low risk following the intervention. Differences in WRMSD risk matrix ratings pre- and post-intervention were significant ($p < 0.01$).

4. Discussion

This study employed a detailed task analysis of the work performed by high voltage overhead powerline workers to develop tailored ergonomics training and implement bespoke engineering-design changes targeted at reducing the risks of WRMSDs. The effectiveness of these interventions was evaluated based on repeated assessment of self-reported musculoskeletal complaints and associated risk factors.

Prior to the interventions, over 50 % of workers in this study reported at least one musculoskeletal complaint of the arms, neck, or hands/wrists. Lower and upper back complaints were considered more severe and occurred more frequently. Following a narrative review of WRMSDs in powerline workers, Padmanathan et al. (2016) concluded that in comparison to other body regions, the back and shoulders appear most affected. The overall 12-month prevalence rates of WRMSDs across studies ranged between 49 % and 70 % (Moriguchi et al., 2009). Interestingly, Moriguchi et al. (2009) found that while the shoulder region was the most affected body part, there was no records of work absenteeism due to these complaints. In contrast, back and knee complaints accounted for 26 % of work absenteeism, which, in line with the current findings, suggest that the severity of symptoms in the shoulder may be less severe and have less of an impact on a person's ability to work.

Musculoskeletal disorders reported by overhead powerline workers have been closely linked to work tasks and the physical demands of the job. Specific tasks, such as bar installation and fixing insulators, and the use of manual presses and manual cutters during cable-cutting, expose workers to awkward postures close to end range of joint motion. These tasks often involve high forces, which are often prolonged and are repeated over the course of a shift (Graves et al., 1996; Padmanathan et al., 2016). Studies have also identified potential environmental (poor weather conditions), psychosocial and work organisational factors that increase the risk of WRMSDs in these workers (Parkhouse and Gall, 2004; Päivinen, 2006; Yu et al., 2009; Padmanathan et al., 2016).

Occupations involving maintenance tasks are commonly associated with a high incidence of WRMSDs due to the variable and unpredictable nature of the work. Abdussalam and Ardiyanto (2024) found that Indonesian railway workers who predominately performed maintenance tasks experienced high rates of lower back (100 %), shoulder (91 %) and knee (88 %) complaints. Over 50 % of these maintenance tasks were categorised as either high or very high risk of musculoskeletal injury.

In the current study, REBA classifications prior to the intervention identified several workers at high risk of WRMSDs when disconnecting powerlines from inside the MEWP. The high-risk ratings were due to operators adopting extended reach, with the arms raised above shoulder height. This was often accentuated by inappropriate positioning of the MEWP (e.g. adopting one position throughout and failing to take into consideration all aspects of the maintenance tasks, as opposed to

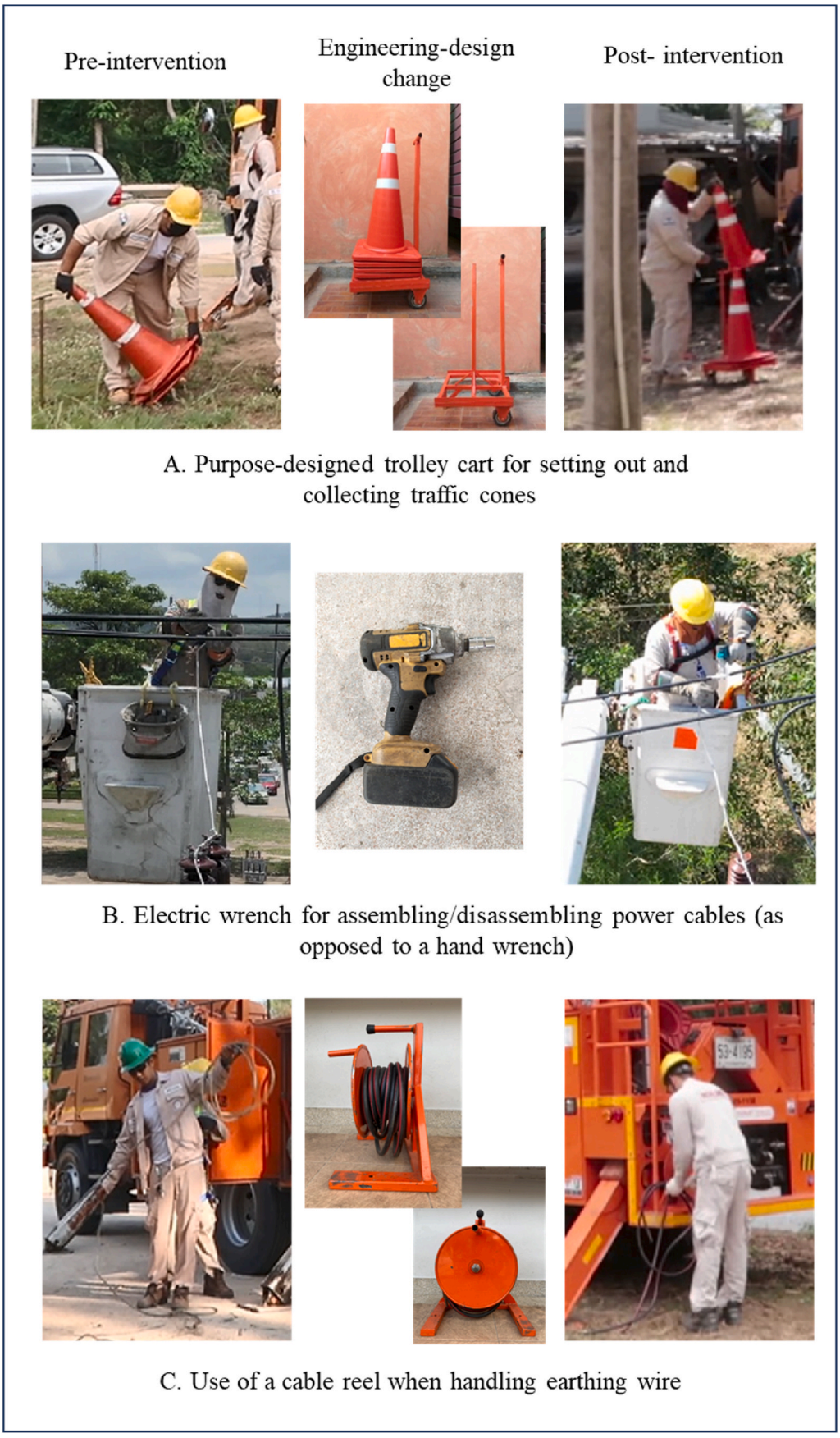

Fig. 2. The engineering-designed changes adopted as part of the intervention programme.

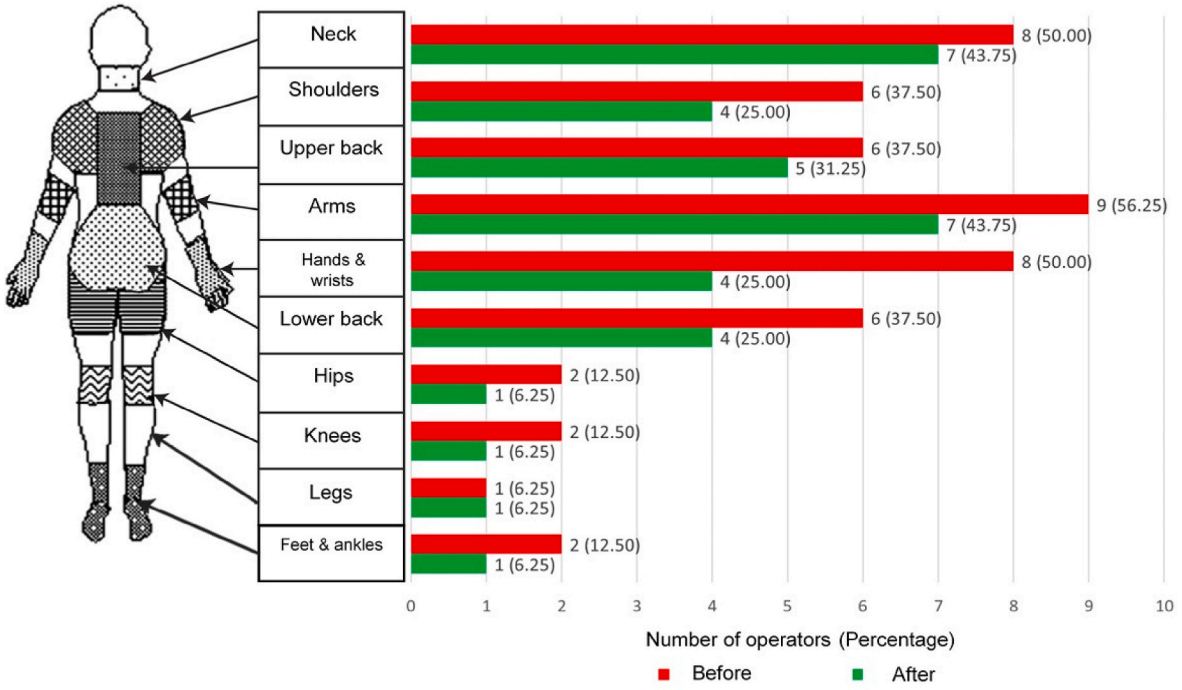

Fig. 3. The number and percentage (bracketted) of powerline workers reporting musculoskeletal discomfort for each body region pre- and post-intervention.

Table 2
Mean (range) REBA scores for each work task and sub-tasks pre- and post-intervention (n = 16).

	Neck Trunk and Legs score (Part A) Median (Min-Max)					Arm and Wrist score (Part B) Median (Min-Max)					Activity score	REBA score
	Neck position	Trunk position	Legs position	Force/load score	Score A	Upper arm position	Lower arm position	Wrist position	Coupling score	Score B		
Work Task 1. Preparation												
Installing traffic cones												
Pre	2 (1–2)	2.5 (2–3)	1 (1–1)	1 (1–1)	4 (3–5)	2.5 (2–3)	2 (2–2)	3 (3–3)	1 (1–1)	5.5 (5–6)	1 (1–1)	7 (5–7)
Post	2 (1–3)	2 (2–3)	1 (1–1)	0 (0–0)	3 (2–4)	4 (2–4)	1 (1–2)	3 (3–3)	1 (1–1)	6 (4–8)	0 (0–0)	5 (4–6)
Installing ground wire												
Pre	2 (2–3)	2 (2–3)	1 (1–2)	0 (0–0)	4 (3–5)	2 (2–2)	1 (1–2)	3 (3–3)	1 (1–1)	4 (4–5)	1 (1–2)	5 (4–7)
Post	2 (1–2)	2 (1–3)	1 (1–1)	0 (0–0)	3 (1–4)	3 (2–3)	2 (2–2)	3 (3–3)	1 (1–1)	6 (5–6)	0 (0–0)	4 (3–5)
Work Task 2. Line working (disconnecting and reconnecting power cables)												
Pre	2 (1–2)	4 (3–4)	1 (1–1)	0 (0–0)	5 (2–5)	5 (4–5)	2 (2–2)	3 (3–3)	1 (1–1)	9 (8–9)	1 (1–2)	9 (7–11)
Post	2 (2–3)	3 (3–4)	1 (1–1)	0 (0–0)	4 (4–5)	4 (3–5)	2 (2–2)	3 (3–3)	0 (0–0)	7 (5–8)	0 (0–0)	7 (5–8)
Work Task 3. Disassembly												
Collecting ground wire												
Pre	2 (2–3)	2 (1–3)	1 (1–1)	0 (0–0)	3 (1–4)	3 (3–5)	2 (2–2)	3 (2–3)	1 (1–1)	6 (6–9)	1 (1–1)	7 (6–7)
Post	2 (1–2)	2 (1–3)	1 (1–1)	0 (0–0)	3 (1–4)	4 (3–4)	2 (2–2)	2 (2–2)	1 (1–1)	6 (5–6)	1 (1–1)	6 (4–6)
Collecting traffic cones												
Pre	2 (1–3)	4 (3–5)	2 (2–2)	1 (1–1)	7 (5–8)	4 (3–5)	2 (2–2)	2 (2–2)	1 (1–1)	7 (6–9)	1 (1–1)	10 (9–11)
Post	2 (2–3)	2 (2–3)	1 (1–1)	0 (0–0)	3 (3–4)	4 (2–4)	2 (1–2)	2 (2–2)	1 (1–1)	6 (4–7)	0 (0–0)	6 (4–6)

adjusting the MEWP to suit the tasks) and the restricted space inside the aerial basket. When working in the MEWP, the handling of heavy and difficult to use hand wrenches and power cables were also considered a potential contributory factor for musculoskeletal complaints. As in the current study, Moriguchi et al. (2009) and Gemma et al. (2019) identified that positioning of the aerial basket resulted in powerline workers frequently adopting static and awkward postures for prolonged periods. As the upper arms and hands were often at a distance from the body and above shoulder level, they concluded that such factors were a likely contributor factor to the high incidence of shoulder discomfort. Working above head height has also been shown to lead to prolonged periods of static, neck extension, which is a proposed reason for the high prevalence of neck complaints in these workers (Moriguchi et al., 2011).

In the current study, the REBA evaluation of manual handling tasks identified the setting out of traffic cones, the installation of a ground wire, and the handling of tools (e.g. wrenches) when inside the MEWP presents a significant risk of musculoskeletal injury. Parkhouse and Gall (2004) found that powerline workers frequently handled tools weighing greater than 20 kg, and sometime as high as 63 kg. When working in the MEWP, the heaviest tools handled weighed 32 kg (Parkhouse and Gall, 2004). Using the Ovako Working Posture Analysis System (OWAS) to evaluate risks associated with WRMSDs, Graves et al. (1996) identified a range of task performed by powerline workers exceeding Action Level 1 ("The load of the posture is slightly harmful: actions to change the postures should be taken in the near future"), including the use of crimping tools and wrenches. These tasks involved extreme postures of the neck, back, shoulders, upper and lower limbs, and required repeated, sustained and forceful exertions away from the body. Biomechanical modelling of forces at the shoulder joint using similar weights to those of crimping tools and with the arms outstretched, resulted in estimated

Table 3
The number (%) of powerline workers classified by the frequency of musculoskeletal discomfort pre- and post-intervention (n = 16).

Body part (s)	Prior-to intervention		Following intervention	
	1–2 times/ week n (%)	3–4 times/ week n (%)	1–2 times/ week n (%)	3–4 times/ week n (%)
Neck	8 (50.0) (2)	0 (0.00)	7 (43.8) (1)	0 (0.0)
Shoulders	6 (37.5) (3)	0 (0.00)	4 (25.0) (3)	0 (0.0)
Upper back	4 (25.0)	2 (12.5) (1)	5 (31.3) (2)	0 (0.0)
Lower back	4 (25.0)	2 (12.5) (1)	2 (12.5)	2 (12.5) (1)
Arms	9 (56.3) (1)	0 (0.0)	7 (43.8) (1)	0 (0.0)
Hands & wrists	8 (50.0) (2)	0 (0.0)	4 (25.00) (3)	0 (0.0)
Hips	2 (12.5)	0 (0.0)	1 (6.3)	0 (0.0)
Knees	2 (12.5)	0 (0.0)	1 (6.3)	0 (0.0)
Legs	0 (0)	1 (6.3) (2)	0 (0.0)	1 (6.3) (2)
Feet & ankles	2 (12.5)	0 (0.00)	1 (6.3)	0 (0.00)

(1),(2),(3) refer to body parts with the 1st, the 2nd, and the 3rd highest ranking at each frequency level.

shoulder forces of up to three times body weight (Graves et al., 1996). Marklin et al. (2004) estimated shoulder forces of more than 300 N when simulating the use of long-handled cable crimpers by powerline operators in the USA. When compared to the shoulder strength capabilities of the general population, it was concluded that less than 1 % of the male and female population would have the strength capabilities to perform crimp connections.

Despite several studies identifying significant risks associated with WRMSDs in powerline workers and proposing recommendations for reducing these risks, there have been few studies that have implemented design changes in practice or evaluated the effectiveness of these interventions. The engineering-designed changes and training provided in the current study resulted in a reduction in the number of musculoskeletal complaints (last 7 days) and a lowering in task-related risk ratings post intervention. The use of assistive devices, such as trolley carts for transporting cones and the use of a battery powered wrenches, were considered relatively inexpensive and therefore, viewed positively by the electrical company. Involvement of workers and senior representatives in the redesign of tasks was considered an important part of the implementation strategy and necessary for the uptake and continued use of the interventions.

Beyond the reduction in risks and the reporting of WRMSDs, few studies have considered the cost-benefits of ergonomic interventions adopted in this group of workers. In a study of powerline operators in the USA, Seeley and Marklin (2003) found that the implementation of battery-operated hand tools (press and cutter) resulted in a return on investment within 4 months, based on medical injury and illness data, workers' compensation, the hiring of workers, and retraining costs (Seeley and Marklin, 2003). A concern often inhibiting the implementation of new ways of working is the additional time needed by workers to adjust and adopt new practices. Whilst employees did take time to adjust to the new ways of working and initially spent longer undertaking tasks, they soon became increasingly proficient in the new methods. As documented elsewhere (Saadatfar et al., 2016), changes to working practices in this study lead to an overall reduction in working time (16 %) and increased efficiency (32 %).

The effectiveness of manual handling training in reducing risks associated with WRMSDs has been questioned. Findings from five systematic reviews (Haslam et al., 2007; Martimo et al., 2008; Clemes et al., 2010; Verbeek et al., 2012; Hogan et al., 2014) have all shown no evidence for the effectiveness of manual handling training in reducing outcome measures across several occupations. However, as Denis et al. (2020) alludes to following a systematic review of 77 manual handling training programmes, the content of these programmes is often uniform, proposing a 'safe' handling technique with little or no attention to the work conditions that might influence behaviour. An important feature of the training programme adopted in this study was the practical, field-based nature of the training that aligned closely to the tasks performed. Furthermore, a detailed assessment of work practices provided the basis on which training was developed and workers gained situational awareness and understanding of their working postures. The follow-up evaluation using REBA scores and risk matrix ratings showed reductions in WRMSD risks across most tasks, an example being the training provided on the adjustment and positioning of the MEWP to reduce leaning and reaching postures. A benefit of using the risk matrix rating is that it incorporates operator self-reported musculoskeletal discomfort, which makes it an attractive tool as part of a WRMSD surveillance programme.

This study has its limitations, primarily due to the small number of powerline workers involved in the study. A post-hoc chi-square analysis (χ^2) was conducted using G*Power (Version 3.1.9.7) (Faul et al., 2007), resulting in estimated power of 80 % using a non-centrality parameter (λ) of 19 (large effect) and an alpha level (α) of 0.05. Another limitation was the time between symptom reporting and the assessment of working practices, which occurred shortly after the interventions (within 1 month). In such instances, positive short-term effects can arise from observer involvement and worker perceptions about the benefits of the interventions. Despite variability within the job, the work tasks appeared consistent in the way they were performed and involved repeated use of the same equipment, which likely led to the noticeable short-term changes in risk scores. Longer-term monitoring (e.g. 6 and 12 months) of symptom reporting would have provided greater insight into the effectiveness of the interventions. Whilst supervisors did reinforce training principles throughout the intervention period, the implementation of these practices was not measured.

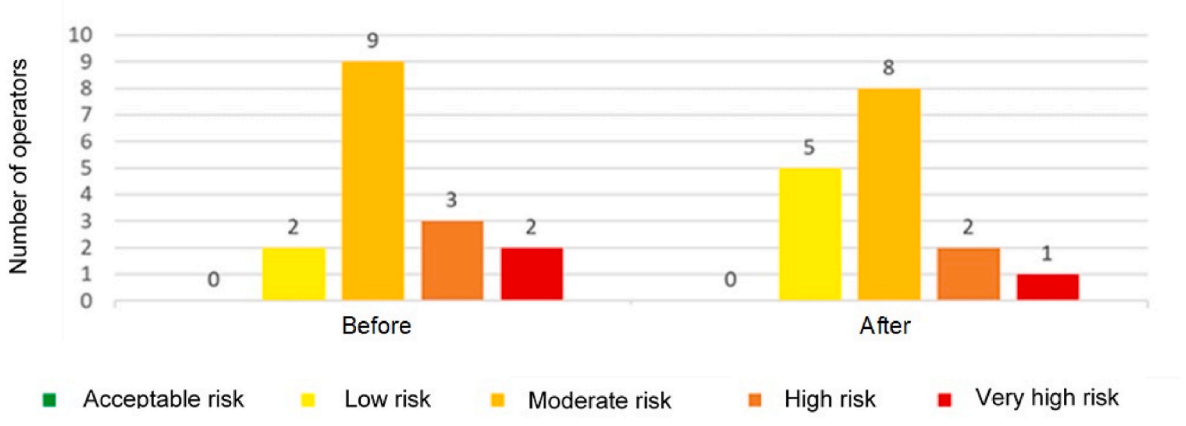

Fig. 4. A comparison of the number of workers reporting WRMSD risk score levels pre- and post-intervention.

To evaluate the risk of musculoskeletal injury, the study used REBA to assess working postures. This was considered the most appropriate method to use as several tasks involved full body activities, did not necessarily involve high force exertions, or two-handed lifting. Whilst there are several observational methods available to assess hazardous manual handling tasks (e.g. the NIOSH lifting equation), they are often restricted in their application (McCormack et al., 2021). For example, the NIOSH lifting equation cannot not be applied to one-handed lifting, high-speed lifts, or lifting in confined spaces, which were evident in many of the tasks observed.

A focus of the study was on modifications to physical risk factors (engineering solutions) and behavioural modifications (training). However, evidence points to several broad categories of risk factors associated with WRMSD causation, including psychosocial, work organisational and contextual factors. Future studies should consider the wide range of potential risk factors associated with WRMSDs and the implementation of multifaceted interventions programmes appropriate to powerline operators.

5. Conclusions

The implementation of engineering-designed changes combined with ergonomics training was effective in reducing the short-term risks associated with WRMSDs in high voltage overhead powerline workers from the Rayong Province of Thailand. The evaluation of tasks pre- and post-intervention indicated improvements in the working practices and postures of workers. The interventions also led to a reduction in WRMSD symptom reporting and the musculoskeletal risk levels for those tasks analysed. Further work is needed to determine the long-term effects of ergonomic interventions on the occupational health of powerline workers, along with the development of strategies for addressing the broader range of risk factors (e.g. psychosocial, work organisation) known to impact on the incidence of WRMSDs.

CRediT authorship contribution statement

Sunisa Chaiklieng: Writing – review & editing, Writing – original draft, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Apiwat Youngwilai:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation. **Mark G. Boocock:** Writing – review & editing, Writing – original draft.

Declaration of competing interest

All authors declare that they have no financial or personal relationships with other people or organisations that could inappropriately influence (bias) this work.

Data availability

Data will be made available on request.

References

Abdussalam, N.M., Ardiyanto, A., 2024. Musculoskeletal symptom survey and ergonomic assessments associated with maintenance tasks in the Indonesian railway industry. Int. J. Occup. Saf. Health 14 (3), 394–403.

Ali, M.F., Samarasena, J., 2019. Implementing ergonomics interventions in the endoscopy suite. Tech. Gastrointest. Endosc. 21 (3), 159–161.

Chaiklieng, S., 2019. Health risk assessment on musculoskeletal disorders among potato-chip processing workers. PLoS One 14 (12), e0224980.

Chaiklieng, S., Pannak, A., Duangprom, M., 2016. The assessment of ergonomics risk on upper limb disorders among electronic workers. Srinagarind Med. J. 31 (2), 202–209.

Chaiklieng, S., Suggaravetsiri, P., Boonprakob, Y., 2010. Work ergonomic hazards for musculoskeletal pain among university office workers. Walailak J. Sci. Technol. 7 (2), 169–176.

Clemes, S.A., Haslam, C.O., Haslam, R.A., 2010. What constitutes effective manual handling training? A systematic review. Occup. Med. 60 (2), 101–107.

Denis, D., Gonella, M., Comeau, M., Lauzier, M., 2020. Questioning the value of manual material handling training: a scoping and critical literature review. Appl. Ergon. 89, 103186.

Energy Policy and Planning Office, 2020. Annual electricity usage statistics report in 2020. from. http://www.eppo.go.th/index.php/th/component/k2/item/16366-energy-statistics-2563.

Faul, F., Erdfelder, E., Lang, A.-G., Buchner, A., 2007. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav. Res. Methods 39 (2), 175–191.

Fordyce, T.A., Leonhard, M.J., Watson, H.N., Mezei, G., Vergara, X.P., Krishen, L., 2016. An analysis of fatal and non-fatal injuries and injury severity factors among electric power industry workers. Am. J. Ind. Med. 59 (11), 948–958.

Fordyce, T.A., Morimoto, L., Coalson, J., Kelsh, M.A., Mezei, G., 2010. Neck injuries among electric utility workers, 1995-2007. J. Occup. Environ. Med. 52 (4), 441–449.

Gemma, S.F.B., Primo, R., Brittes, J.L.P., Misuta, M.S., Junior, E.P.L., 2019. Ergonomic and psychosocial aspects of electrical energy maintenance activities on transmission lines. Advances in Intelligent Systems and Computing. Springer Verlag, pp. 1757–1760.

Graves, R., De Cristofano, A., Wright, E., Watt, M., White, R., 1996. Potential musculoskeletal risk factors in electricity distribution linesmen tasks. Contemporary Ergonomics. CRC Press, S. A. Robertson, pp. 215–220.

Haslam, C., Clemes, S., McDermott, H., Shaw, K., Williams, C., Haslam, R., 2007. Manual Handling Training: Investigation of Current Practices and Development of Guidelines. HMSO, Norwich, UK. Report number: RR583.

Hignett, S., McAtamney, L., 2000. Rapid Entire Body Assessment (REBA). Appl. Ergon. 31 (2), 201–205.

Hogan, D.A., Greiner, B.A., O'Sullivan, L., 2014. The effect of manual handling training on achieving training transfer, employee's behaviour change and subsequent reduction of work-related musculoskeletal disorders: a systematic review. Ergonomics 57 (1), 93–107.

Homsombat, T., Chaiklieng, S., 2017. Physical fitness and muscular discomfort among informal garment female workers in Udon Thani province, Thailand. J. Med. Assoc. Thail. 100 (2), 230–238.

Kelsh, M.A., Lu, E.T., Ramachandran, K., Jesser, C., Fordyce, T., Yager, J.W., 2004. Occupational injury surveillance among electric utility employees. J. Occup. Environ. Med. 46 (9), 974–984.

Marklin, R.W., Lazuardi, L., Wilzbacher, J.R., 2004. Measurement of handle forces for crimping connectors and cutting cable in the electric power industry. Int. J. Ind. Ergon. 34 (6), 497–506.

Martimo, K.P., Verbeek, J., Karppinen, J., Furlan, A.D., Takala, E.P., Kuijer, P.P., Jauhiainen, M., Viikari-Juntura, E., 2008. Effect of training and lifting equipment for preventing back pain in lifting and handling: systematic review. Br. Med. J. 336 (7641), 429–431.

McCormack, P., Read, G.J.M., Salmon, P.M., Goode, N., 2021. Do hazardous manual handling task risk assessment methods align with systems thinking? Saf. Sci. 140.

Moriguchi, C.S., Alencar, J.F., Miranda-Júnior, L.C., Coury, H.J.C.G., 2009. Musculoskeletal symptoms among energy distribution network linemen. Rev. Brasileira Fisioterapia 13 (2), 123–129.

Moriguchi, C.S., Carnaz, L., cia, Alencar, J.F.d., Miranda, J., Nior, L.C., Granqvist, L., Hansson, G., keGil Coury, H.J.C., 2011. Postures and movements in the Most common tasks of power line workers. Ind. Health 49 (4), 482–491.

Moriguchi, C.S., Carnaz, L., Veiersted, K.B., Hanvold, T.N., Haeg, L.B., Hansson, G.A., Cote Gil Coury, H.J., 2013. Occupational posture exposure among construction electricians. Appl. Ergon. 44 (1), 86–92.

Padmanathan, V., Joseph, L., Omar, B., Nawawi, R., 2016. Prevalence of musculoskeletal disorders and related occupational causative factors among electricity linemen: a narrative review. Int. J. Occup. Med. Environ. Health 29 (5), 725–734.

Päivinen, M., 2006. Electricians' perception of work-related risks in cold climate when working on high places. Int. J. Ind. Ergon. 36 (7), 661–670.

Parkhouse, W., Gall, B., 2004. Task frequency as a function of age for the powerline technician trade. Ergonomics 47 (6), 660–670.

Poochada, W., Chailklieng, S., 2022. Self-reported musculoskeletal disorders questionnaire for agriculturists: an online self-assessment tool development. PLoS One 17 (12), e0277548.

Saadatfar, A., Ranjbarian, M., Saremi, M., Hashemian, A., Yazdian, A., 2016. Risk assessment of musculoskeletal disorders in linemen of electric power distribution company of Kermanshah province using REBA method in 2015. J. Rafsanjan Univ. Med. Sci. 15 (7), 593–606.

Seeley, P.A., Marklin, R.W., 2003. Business case for implementing two ergonomic interventions at an electric power utility. Appl. Ergon. 34 (5), 429–439.

Verbeek, J., Martimo, K.P., Karppinen, J., Kuijer, P.P., Takala, E.P., Viikari-Juntura, E., 2012. Manual material handling advice and assistive devices for preventing and treating back pain in workers: a cochrane systematic review. Occ. Environ. Med. 69 (1), 79–80.

Volberg, V., Fordyce, T., Leonhard, M., Mezei, G., Vergara, X., Krishen, L., 2017. Injuries among electric power industry workers, 1995–2013. J. Saf. Res. 60, 9–16.

Yu, M., Sun, L., Du, J., Wu, F., 2009. Ergonomics hazards analysis of linemen's power line fixing work in China. Int. J. Occup. Saf. Ergon. 15 (3), 309–317.