Agronomy Research **14**(x), xx–xx, 2016

Ergonomics risk analysis in construction operations

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Abstract. The research focuses on analysis of ergonomics risks among construction workers in different operations at work. The aim of the research is to carry out ergonomics risk analysis in various construction operations and to prove that physically hard manual work and application of force in manual work operations affect muscular fatigue, using objective and subjective risk assessment methods, including extended version of Nordic musculoskeletal questionnaire, myotonometric measurements, muscle's force determination with dynamometer. During the research it was proved that the combination of objective and subjective ergonomics risk analysis methods provides holistic approach and reliable ergonomics risk analysis results.

Key words: Ergonomics, construction, risk, hand grip

INTRODUCTION

In Latvia, number of employees in construction works is one of the highest in comparison to other branches of the national economics. In this branch, number of occupational diseases caused by overload has grown rapidly regardless of the automation and mechanization of many processes. In the last decade work related musculoskeletal disorders (WRMSD) every year comprise about 65% of the total number of occupational diseases in the country. Analysis of literature reveals that such diseases are more common in construction than in any other industrial sector, except transportation, and that construction workers comprise the highest risk group for work related musculoskeletal disorders, including lower back pain (Goldsheyder et al., 2002; Henker et al., 2005). Review of the injury data showed that construction workers experience musculoskeletal injuries at a rate about 50% higher than manufacturing workers (Sneider, 2001). In a British study, the 1-year cumulative incidence of lower back pain was 40% among construction workers as compared with 28% among foremen (Macfarlane, 1997). Construction workers are usually engaged in an uncomfortable posture. They lift and move heavy loads with hands, as well as often perform repeated actions and during the work apply considerable hand forces. These conditions are intensified by work in unstable environment. Studies show that grip force declines after midlife, with loss, accelerating with increasing age and through old age (Roberts et al., 2011). Grip force is related to other health conditions, but the relationship has not been stated to be causative (Bohannon, 2008). Hand grip force is negatively associated with physical frailty, even when the effects of body mass index (BMI) and arm muscle circumference are removed (Syddall et al., 2003). Hand grip force can be quantified by measuring the amount of static force with which the hand can squeeze around a dynamometer (Lescinskis et al., 2012). Hand grip force is a reliable measurement when standardised methods and calibrated equipment are used, even when there are different assessors (Mathiowetz, 2002) or different brands of dynamometers (Schmidt et al., 2002). Researchers have suggested that the factor, related to frailty and disability in later life, is the manner in which muscles are used, and this can be measured by hand dynamometry that will be applied in this research. WRMSDs cause deterioration of health, which manifests as chronic pain in certain body parts and premature muscle fatigue, thus increasing the costs of absenteeism due to less productivity at work (Punnett & Wegman, 2004; Roja et al., 2006; Kalkis, 2014).

Therefore ergonomics intervention in construction processes is important in order to promote employees' health, safety and to increase productivity (Lussier, 2014). Ergonomics risk analysis at work and work processes ensures employee's wellbeing, sense of belonging and trust to the organisation (Kalkis., 2008; Roja, 2008; Kalkis, 2014).Various studies in the world prove that the effectiveness of the organisation is closely related to a human as the performer of work duties, and his or her skills and health affect business results of organisation (Sperry, 2002).

The research focuses on analysis of ergonomics risks among construction workers in different operations at work.

The aim of the research is to carry out ergonomics risk analysis in various construction operations and to prove that physically hard manual work and application of force in manual work operations affect muscular fatigue, using objective and subjective risk assessment methods.

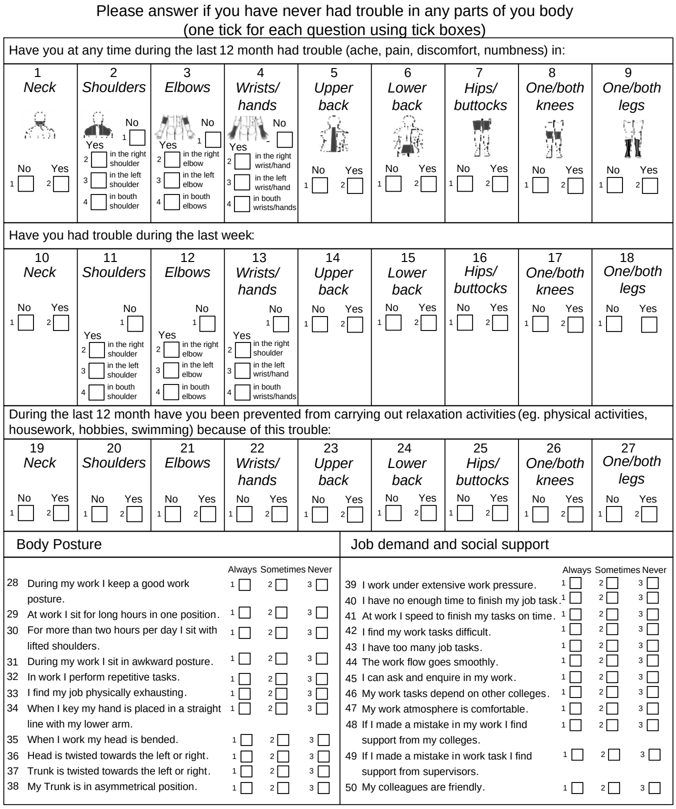
The study was conducted in one of the Latvian construction organisations. The study involved 7 assemblers and 8 building workers (see Table 1). All of them agreed to participate in the experiment with objective evaluation methods. Criteria for selection of the persons to be studied were: whether the person has been suffering from persistent pain in musculoskeletal system for more than three months according to complaints and objective findings during compulsory check-ups, length of service in the profession, employee's consent to participate in the study. None of the research participants had any upper limb pathology or dysfunction. All persons were right-handers. Persons were excluded from the study in such cases: the employees not having health checkups, persons with acute pain and with specific muscular and skeletal diseases.

This study was conducted in accordance with ethical standards and was approved by the Riga Stradins University Ethical Committee in 2015.

MATERIALS AND METHODS

1. Extended version of Nordic musculoskeletal questionnaire (NMQ-E). This questionnaire was used to assess musculoskeletal problems in construction workers and assemblers (the nature and severity of self-rated musculoskeletal symptoms, including items inquiring about the experience of problems in nine body areas) (Kuorinka et.al.,

1987). In our study, the extended version of NMQ-E contains some additional questions regarding body postures, job demands and social support (see Fig. 1).



Please answer if you have never had trouble in any parts of you body
(one tick for each question using tick boxes)

Have you at any time during the last 12 month had trouble (ache, pain, discomfort, numbness) in:

1 *Neck*	2 *Shoulders*	3 *Elbows*	4 *Wrists/ hands*	5 *Upper back*	6 *Lower back*	7 *Hips/ buttocks*	8 *One/both knees*	9 *One/both legs*
No 1 ☐ Yes 2 ☐	No 1 ☐ Yes 2 ☐ in the right shoulder 3 ☐ in the left shoulder 4 ☐ in bouth shoulder	No 1 ☐ Yes 2 ☐ in the right elbow 3 ☐ in the left elbow 4 ☐ in bouth elbows	No 1 ☐ Yes 2 ☐ in the right wrist/hand 3 ☐ in the left wrist/hand 4 ☐ in bouth wrists/hands	No 1 ☐ Yes 2 ☐	No 1 ☐ Yes 2 ☐	No 1 ☐ Yes 2 ☐	No 1 ☐ Yes 2 ☐	No 1 ☐ Yes 2 ☐

Have you had trouble during the last week:

10 *Neck*	11 *Shoulders*	12 *Elbows*	13 *Wrists/ hands*	14 *Upper back*	15 *Lower back*	16 *Hips/ buttocks*	17 *One/both knees*	18 *One/both legs*
No 1 ☐ Yes 2 ☐	No 1 ☐ Yes 2 ☐ in the right shoulder 3 ☐ in the left shoulder 4 ☐ in bouth shoulder	No 1 ☐ Yes 2 ☐ in the right elbow 3 ☐ in the left elbow 4 ☐ in bouth elbows	No 1 ☐ Yes 2 ☐ in the right shoulder 3 ☐ in the left wrist/hand 4 ☐ in bouth wrists/hands	No 1 ☐ Yes 2 ☐	No 1 ☐ Yes 2 ☐	No 1 ☐ Yes 2 ☐	No 1 ☐ Yes 2 ☐	No 1 ☐ Yes ☐

During the last 12 month have you been prevented from carrying out relaxation activities (eg. physical activities, housework, hobbies, swimming) because of this trouble:

19 *Neck*	20 *Shoulders*	21 *Elbows*	22 *Wrists/ hands*	23 *Upper back*	24 *Lower back*	25 *Hips/ buttocks*	26 *One/both knees*	27 *One/both legs*
No 1 ☐ Yes 2 ☐	No 1 ☐ Yes 2 ☐	No 1 ☐ Yes 2 ☐	No 1 ☐ Yes 2 ☐	No 1 ☐ Yes 2 ☐	No 1 ☐ Yes 2 ☐	No 1 ☐ Yes 2 ☐	No 1 ☐ Yes 2 ☐	No 1 ☐ Yes 2 ☐

Body Posture

	Always	Sometimes	Never
28 During my work I keep a good work posture.	1 ☐	2 ☐	3 ☐
29 At work I sit for long hours in one position.	1 ☐	2 ☐	3 ☐
30 For more than two hours per day I sit with lifted shoulders.	1 ☐	2 ☐	3 ☐
31 During my work I sit in awkward posture.	1 ☐	2 ☐	3 ☐
32 In work I perform repetitive tasks.	1 ☐	2 ☐	3 ☐
33 I find my job physically exhausting.	1 ☐	2 ☐	3 ☐
34 When I key my hand is placed in a straight line with my lower arm.	1 ☐	2 ☐	3 ☐
35 When I work my head is bended.	1 ☐	2 ☐	3 ☐
36 Head is twisted towards the left or right.	1 ☐	2 ☐	3 ☐
37 Trunk is twisted towards the left or right.	1 ☐	2 ☐	3 ☐
38 My Trunk is in asymmetrical position.	1 ☐	2 ☐	3 ☐

Job demand and social support

	Always	Sometimes	Never
39 I work under extensive work pressure.	1 ☐	2 ☐	3 ☐
40 I have no enough time to finish my job task.	1 ☐	2 ☐	3 ☐
41 At work I speed to finish my tasks on time.	1 ☐	2 ☐	3 ☐
42 I find my work tasks difficult.	1 ☐	2 ☐	3 ☐
43 I have too many job tasks.	1 ☐	2 ☐	3 ☐
44 The work flow goes smoothly.	1 ☐	2 ☐	3 ☐
45 I can ask and enquire in my work.	1 ☐	2 ☐	3 ☐
46 My work tasks depend on other colleges.	1 ☐	2 ☐	3 ☐
47 My work atmosphere is comfortable.	1 ☐	2 ☐	3 ☐
48 If I made a mistake in my work I find support from my colleges.	1 ☐	2 ☐	3 ☐
49 If I made a mistake in work task I find support from supervisors.	1 ☐	2 ☐	3 ☐
50 My colleagues are friendly.	1 ☐	2 ☐	3 ☐

Figure 1. Musculoskeletal questionnaire (Roja et al., 2013).

2. Assessment of the functional state of skeletal muscles and muscle fatigue was carried out using myotonometric measurements with the MYOTON-3 device. (Vain, 1995; Roja at al., 2006).

3. Grip force as assessment technique is recommended for the measurement of muscle strength, and is one of the simplest methods for assessment of muscle function (Bohannon, 2008).The Camry Electronic Hand Dynamometer for Hand Grip Force evaluation was used in the study. With Dynamometer high-precision power gauging gives momentary digital readouts of gripping power and auto capturing of maximum achieved grip power and display of the value. The testing has been done in the standing position with the examinee holding the dynamometer: the person, at shoulder height, stretches out the arm to the side and holds the dynamometer in the hand; not bending the arm, the person squeezes the digital spring of the dynamometer with maximum strength. On its scale the examiner reads the amount of the applied muscle force (kg). Muscle force was determined 3 times for each arm separately and the average result recorded (Roberts et al, 2011).

The room temperature was 22 °C. The average value of the three repetitions has been calculated and used in this study. Measurements were made with measure tape with 0.1cm precision.

Each worker was tested individually in the morning before the shift and in the evening after the work shift at the same time of the day during 1 week cycle. The same examiner performed all measurements.

RESULTS AND DISCUSSION

Background factors of the research group are shown in Table 1.

Table 1. Background factors of the research groups, mean age and range, length of service, mean height, mean weight, mean body mass index (BMI)

Professions	n	Mean age ± SD	Range	Mean length of service ± SD	Mean height, cm ± SD	Mean weight, kg ± SD	Mean BMI, kg m^{-2} ± SD
Construction worker	8	35.3 ± 5.8	26-45	6.8 ± 3.5	176.2± 6.3	79.4±11.2	25.5±3.3
Assembler	7	36.4±7.7	23-38	6.8 ± 4.6	178.0±9.5	76.1±5.1	24.2±2.1

The main duties of construction workers were the following: loading and unloading of construction supplies with hands, making of building structures, carrying of construction supplies and taking away of waste materials. Generally, construction workers' hands were loaded with physically hard work. The main duties of assemblers were related with drilling, tightening of screws assembling building structures, and utilities. Generally, assemblers' work is performed in awkward postures, very often with arms raised above the shoulder level.

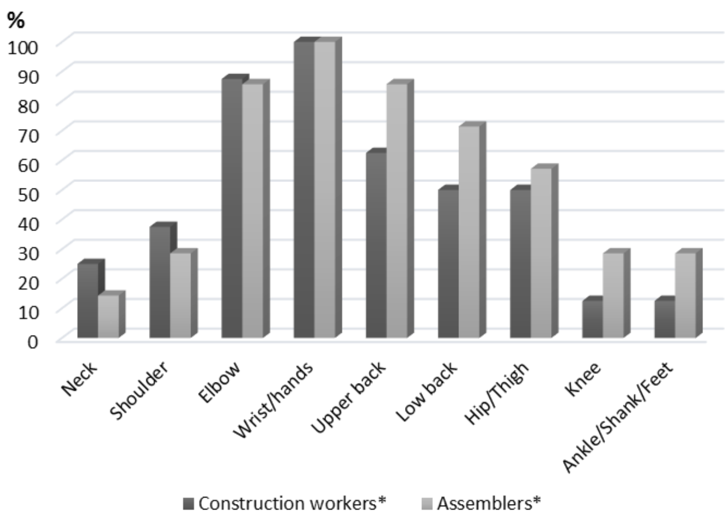


Figure 2. Distribution of persistent complaints in different parts of the body of construction workers and assemblers (*Multiple answers were possible).

The distribution of persistent complaints in each part of the body, separately for construction workers and assemblers, according to the extended version of Nordic musculoskeletal questionnaire NMQ-E was shown in the Fig. 2.

The acquired survey results suggest that during work construction workers' and assemblers' arms are most loaded in the area of elbows and base of the hand, respectively 87.50% and 85.71%. All employees (100%), involved in the study, complain of the load of arms. Construction workers complain also of the load in the upper and the lower back, respectively, 85.70% and 71.40%. Distribution of postures, job demand and social support for construction workers and assemblers are shown in Fig. 3.

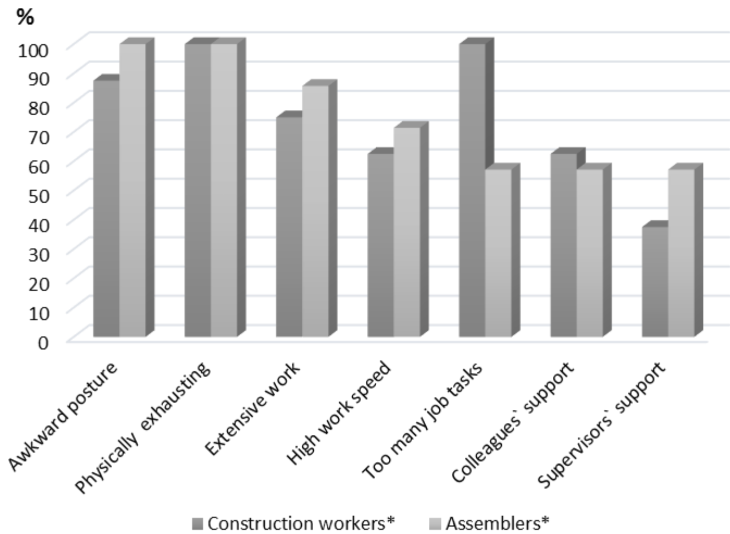


Figure 3. Distribution of postures, job demand and social support for construction workers and assemblers (*****Multiple answers were possible).

It should be noted that employees of both professions work in awkward posture (see Table 3). Generally, all employees have high work intensity (85.71% and 75.00%) at high speed of work. Half of the employees mention insufficient support from colleagues and management.

Using the Myoton-3 device and gathered investigation data during the one week work cycle (from Monday to Friday), it is possible to determine change in muscle tone, the workers' capacity for work, the ability to adapt to the work rhythm and work load, as well as the moment when muscle fatigue sets in. It is noted that the natural oscillation frequency of muscles in their functional state of relaxation is usually 11−16 Hz (contracted 18−40 Hz), depending on the muscle. The stiffness values depend significantly on the muscle under investigation, their usual range is 150−300 N m^{-1}. For the contracted muscles the stiffness value can be higher than 1,000 N m^{-1}. The decrement values, calculated from the measurement results, are usually not higher than 1.0−1.2, depending on the muscle. In case of trained muscles, the decrement of contracted muscles decreases (e.g. from 1.0 to 0.6), i.e. the muscle elasticity increases.

According to regression analysis, the trend line reflects the condition of the muscles after one week work cycle for all workers and can be subdivided into several MYO categories (Roja at al., 2006):

Category I – absolute muscle relaxation with the ability to relax;

Category II – a state of equilibrium, when muscles are able to adapt to the work load and are able to relax partly;

Category III – muscle fatigue and increase in tone.

Since representatives of both professions mainly complain of pain or discomfort in the arms and upper back, it was decided to make objective measurements with Myoton-3 equipment, evaluating adaptability of the muscles (*m. extensor digitorum*, *m. flexor carpi radialis*, *m. trapezius*) to work load. In the 'Results and discussion' section all pertinent results should be presented in a logical order and discussed. Discussion portion could also include significance of the results in context of the research field, and suggestions for the future research.

The comparison of different muscle groups after one-week work cycle, when the frequency and stiffness go beyond the norm, is represented in Table 2. Subjective viewpoint of the workers is pronounced as acceptance (pac, %).

Table 2. Percentage of workers whose muscle frequency exceeds the norm (>16 Hz) after one-week work cycle.

Muscle groups	Construction workers (n=8)			Assemblers (n=7)		
	%	κ	p_{ac}	%	κ	p_{ac}
m. extensor digitorum	75.00	0.64	62.50	85.71	0.59	71.43
m. flexor carpi radialis	87.50	0.51	75.00	85.71	0.65	71.43
m. trapezius	87.50	0.70	87.50	85.71	0.53	85.71

Analysis of the data shows that for the construction workers and assemblers the greatest load was put on arm muscles *m. extensor digitorum* and *m. flexor carpi radialis*. In this case, the normal frequency was exceeded by 75.00%–87.50% in construction workers, and by 85.71% in assemblers. Myotonometric measurements also showed that *m. trapezius* frequency exceeded the norm in both groups respectively, 87.50% in construction workers and 85.71% in assemblers.

The percentage of the construction workers and assemblers with difference in their muscle tone (MYO categories) before and after one work-cycle is shown in Table 3.

Table 3. Percentage of construction workers (n = 8) and assemblers (n = 7) with difference in their muscle tone (MYO Categories) before and after one work-cycle, and Cohen's Kappa (κ)

Category	κ
Construction workers:	
I –12.50%	0.33
II − 37.50%	0.68
III − 50.0%	0.51
Assemblers:	
I –14.29%	0.86
II − 28.57%	0.69
III − 57.14%	0.75

Myotonometric analysis shows that nearly in all employees muscles are not able to adapt to the work load, which corresponds to II and III MYO Category. In 37.50% of construction workers and 28.57% of assemblers muscles are able to adapt to the work load and are able to relax partly, but in 50.00% of construction workers and 57.14% of assemblers muscle fatigue and muscle tone drastically increased. It should be noted that the mentioned changes occurred in younger employees with length of service 0-5 years. It could be explained by the fact that the younger employees are beginners and have not used to physical work load and they have not had physical work experience.

Since most of the employees in the survey complain of the load on the hands, in order to find out hand grip muscle force dynamometric method was applied. Acquired results are shown in Table 4.

Table 4. Hand grip muscle force measurements in one -week work cycle for construction workers and assemblers

Days	Hand grip muscle force, kg in one-week cycle (Monday till Friday) Construction workers				Hand grip muscle force, kg in one-week cycle (Monday till Friday) Assemblers			
	Morning		Evening		Morning		Evening	
	Right	Left	Right	Left	Right	Left	Right	Left
Monday	52.6 ± 3.9	52.4 ± 4.2	52.6 ± 5.6	49 ± 6.9	48.5 ± 4.5	46± 4.2	43.3 ± 3.1	33.6 ± 6.1
Tuesday	54 ± 5.3	53.6 ± 8.7	55.8 ± 7.3	44 ± 3.8	59.2 ± 3.2	50.6 ± 5.2	40 ± 5.7	36.4 ± 3.5
Wednesday	54 ± 5.6	49.9 ± 5.1	52.5 ± 2.6	39.7 ± 5.3	48.8 ± 3.3	47.4 ± 4.9	36.8 ± 4.8	42.4 ± 7.1
Thursday	59.9 ± 6.4	58.4 ± 4.6	44.1 ± 4.8	44.5 ± 3.6	59 ± 5.2	50.3 ± 4.1	42 ± 3.7	41.3 ± 3.5
Friday	54.4 ± 8.7	47.8 ± 3.5	53.1 ± 5.5	45.3 ± 4.5	50.9 ± 6.9	56.2 ± 6.3	49.6 ± 5.8	47 ± 4.6

Analysis of hand grip muscle force shows that before and after carrying out of work duties within the period of one week hand grip muscle force of nearly all employees was in norm, except in one construction worker (aged 43, length of service 10 yrs) and in one assembler (aged 38, length of service 8 yrs). In most of the employees (7 construction workers and 6 assemblers) hand grip muscle force results in the right hand are higher than in the left hand. In few cases, though none of the employees is a left-hander, hand grip muscle force in left hand was greater than that in the right hand. In general, the acquired results suggest that hand grip force within the one-week work cycle decreases.

The acquired results correspond with published normative data for hand grip force available from many countries, and in most cases, data are divided into age and gender subgroups (Mathiowetz et al, 1985). Analysis of grip force by gender shows higher grip by males at all ages, and analysis by age group demonstrates high grip force in the age group starting from 40 years (Bohannon et al, 2006). Such trend has also been found in other studies that divide participants by age, gender, by right and left hand, dominant and non-dominant hand.

CONCLUSIONS

Research proved that construction workers are subjected to various ergonomic risks, including long and intensive work hours, awkward postures, and frequent movements. Construction workers and assemblers have persistent complaints in various body parts (highest scores by NMQ-E questionnaire: wrists, hands, upper back, low back), lack social support (colleagues` and supervisors` support) and have high work speed and too many job tasks that results in negative effect on physical and mental workload.

The acquired results with dynamometer on hand grip muscle force correspond with myotonometric measurements of muscle fatigue and prove that in construction workers muscle tone within one-week work cycle decreases, and hand grip muscle force decreases as well. It proves the setting in of muscle fatigue in construction workers and assemblers in various construction operations.

Objective measurements with devices Myoton-3 and Dynamometer are suitable for determination of the muscle fatigue and the applied force in construction workers and assemblers in various construction operations. The combination of objective and subjective ergonomics risk analysis methods provides holistic approach and reliable ergonomics risk analysis results.

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