BMJ Open

Influence of co-exposure to long working hours and ergonomic risk factors on musculoskeletal symptoms: An interaction analysis

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2021-055186
Article Type:	Original research
Date Submitted by the Author:	05-Jul-2021
Complete List of Authors:	Park, Jeongwoo; Dong-A University College of Medicine, Cho, Seong-Sik; Dong-A University, Department of Occupational and Environmental Medicine Kang, Mo-Yeol ; Catholic University of Korea College of Medicine, Occupational and environment meidcine Kim, Jung Il; Dong-A University College of Medicine, Department of Occupational & Environmental Medicine Hwang, Jong-Hyun ; Dong-A University College of Medicine, Occupational and environmental medicine
Keywords:	EPIDEMIOLOGY, OCCUPATIONAL & INDUSTRIAL MEDICINE, Musculoskeletal disorders < ORTHOPAEDIC & TRAUMA SURGERY

SCHOLARONE™
Manuscripts

Influence of co-exposure to long working hours and ergonomic risk factors on musculoskeletal symptoms: An interaction analysis

Jeong-Woo Park, MD[1]; Mo-Yeol Kang, MD[2]; Jung-Il Kim, MD[1]; Jong-Hyun Hwang, MD[3]; Seong-Sik Cho, MD[1]*

[1]Department of Occupational and Environmental Medicine, College of Medicine, Dong-A University, Busan, Korea

[2]Department of Occupational and Environmental Medicine, Seoul St. Mary's Hospital, College of Medicine, The Catholic University of Korea, Seoul, Korea

[3]Department of Occupational and Environmental Medicine, Dong-A University hospital, Busan, Korea

***Corresponding Author**: Seong-Sik Cho

Department of Occupational and Environmental Medicine, College of Medicine

Dong-A University

32 Daesingongwon-ro, Seo-gu, Busan 49201, Korea

Phone: 82 10-4920-9725

Fax: 051-242-8428

Email: sscho@dau.ac.kr

Word Count (excluding title page, abstract, references, figures and tables): 2310 words

ABSTRACT

Background: This study was conducted to explore the combined effect of ergonomic risk factors and long working hours on musculoskeletal symptoms, as this co-exposure remains understudied.

Methods: This study analyzed data of 34,316 participants from the fifth Korean Working Condition Survey. To assess the combined effect of ergonomic risk factors and long working hours on musculoskeletal symptoms, the relative excess risk due to interaction (RERI) and the ratio of odds ratios (ORs) were calculated using multiple survey-weighted logistic analysis and post-estimation commands. Other confounding variables such as age, sex, education level, income, shift work, and employment status were analyzed.

Results: The OR for musculoskeletal symptoms was 1.75 (95% confidence interval [CI] = 1.28–1.39) for exposure to long working hours, 3.49 (95% CI = 3.06–3.99) for exposure to ergonomic risk factors, and 5.07 (95% CI = 4.33–5.93) for co-exposure to long working hours and ergonomic risk factors. The RERI was 0.82 (95% CI = 0.11–1.53), and the ratio of ORs was 0.83 (95% CI = 0.50–1.14)

Conclusion: Our findings suggest that co-exposure to both ergonomic risk factors and long working hours has a supra-additive interaction effect on musculoskeletal symptoms.

Key terms: populations at risk; surveys and questionnaires

Strength & Limitation of this study

This study analyzed a nationally representative sample (the KWCS) with a large-sample size (34,316).

This study conducted interaction analysis in both additive and multiplicative scales.

The causality between exposures and musculoskeletal disorders could not be established due to the study design (a cross-sectional study).

Self-reporting of working hours and musculoskeletal symptoms may lead to information bias.

The potential confounders, such as body mass index, previous history of musculoskeletal diseases, were not assessed in this study.

KEY MESSAGES

What is already known on this subject?

Long working hours and ergonomic risk factors are associated with musculoskeletal symptoms.

What this study adds?

This study found that long working hours and ergonomic risk factors had a negative synergistic effect on musculoskeletal symptoms due to their interaction. The results of the study suggest that stricter regulations on working are essential for workers who are exposed to ergonomic risk factors.

INTRODUCTION

Musculoskeletal disorders are an important work-related health issue worldwide, as they increase medical costs due to their high prevalence.[1] Work-related musculoskeletal disorders account for 40% of all work-related medical expenses worldwide.[2] In South Korea, they accounted for 57.6% of all work-related diseases in 2018.[3] A variety of risk factors, including physical and psychosocial factors, are associated with musculoskeletal disorders. Ergonomic risk factors, such as awkward or painful posture, heavy physical workload, lifting and forceful movements, and repetitive hand or arm movements, are well-known risk factors of musculoskeletal disorders.[4] Moreover, an increased risk of developing work-related musculoskeletal disorders is linked to psychosocial factors, including poor job control and low social support.[5, 6]

Long working hours can be harmful to workers' health and well-being, and are linked to physical health problems such as atrial fibrillation, coronary heart disease, stroke, occupational injury, depression, and suicidal ideation.[7–11] The Korean government has acknowledged the adverse effects of excessive working hours and has legally stipulated a maximum of 52 working hours per week. However, the average annual working hours in Korea was still 1,967 hours in 2019, which is 241 more hours than in OECD countries.[12]

Long working hours imply that workers in a hazardous working environment are exposed to risks for longer periods. Thus, co-exposure to long working hours combined with other occupational risk factors could be more harmful. From this perspective, co-exposure to long working hours and ergonomic risk factors may lead to a higher prevalence of musculoskeletal disorders in the workplace. However, few studies have reported the combined effect of long working hours and ergonomic risk factors on musculoskeletal

disorders, particularly using both additive and multiplicative scales. Thus, this study aimed to identify the combined effect of long working hours and ergonomic risk factors on musculoskeletal symptoms by interaction analysis, on both additive and multiplicative scales.

METHODS

Study participants

We used a data sample from the fifth Korean Working Condition Survey (KWCS), conducted by the Korea Occupational Safety and Health Agency (KOSHA). The KWCS is comparable to the European Working Conditions Survey; it aims to survey the working conditions in various occupations. The sample from the fifth KWCS was recruited from 17 cities and provinces in Korea and excludes individuals younger than 15 years.

The target population included nationwide employed individuals aged 15 years or older in all Korean households in 2017. The survey was conducted through face-to-face interviews after obtaining consent from the participants. Students, stay-at-home spouses, unemployed, and retired individuals were excluded to ensure that the sample represented the economically active population. A sample design was constructed using a secondary probability proportion stratified cluster sample survey. Census districts were chosen based on the number of households. Thereafter, in each selected census district, 10 households were randomly selected. Finally, interviews were conducted with one eligible person in each household. The data of the fifth KWCS used design-weight to adjust the non-response rate and sample selection. In addition, the raking ratio method was used for post-stratification to adjust for the characteristics of gender, age, region, locality, and occupation.

Of the total 50,205 employees (unweighted sample size = 50,205), 34,316 wage workers (unweighted sample size = 27,927)—excluding self-employed, unpaid family workers, and employers—were included in the analysis. Only employees whose weekly working hours totaled more than 30 hours were included to exclude the impact of incomplete employment.

Ethical considerations

The data used in our study are fifth Korean working condition survey which is open to the public with personally identifiable information deleted. The need for written informed consent was waived off and this study was approved by the Institutional Review Board of Dong-A University Hospital (Approval No: DAUHIRB-TEMP-20-212).

Study variables

All study variables were collected from the KWCS questionnaire. Sociodemographic variables included gender, age, educational level, and income. Age was divided into five categories: <30, 30–39, 40–49, 50–59, ≥60. Education was classified according to three levels: middle school or less, high school graduate, or college or more. Monthly income was categorized into quartiles. Employment status was classified into three categories: regular, temporary, and daily. Shift work was classified into two categories (yes or no). The information about working hours per week was collected using the following question: “How many hours do you work per week?” Answers were divided into two categories: 30–52 h/week was classed as “standard working hours,” while more than 52 h/week was classed as “long working hours.”

Exposure to ergonomic risk factors was assessed using a questionnaire. First, the percentage of time that workers were exposed to a specific motion or posture during their working time was recorded. There were five items assessing ergonomic risk factors, namely tiring or painful position, lifting or moving people, carrying or moving heavy loads, continuous standing, and repetitive hand or arm movements.[4] For each item, the results were dichotomized into "with exposure" when the exposure time was half of the working hours or more per day, or "without exposure" when the exposure time was less than half of the working hours per day. Finally, if any of the five items were reported as "with exposure," "ergonomic risk factor" was considered present, while if all five items were reported as "without exposure," "ergonomic risk factor" was considered not present.

Musculoskeletal symptoms were present when workers had any of the three following symptoms: neck and upper limb (shoulder, arm, elbow, wrist, hand) pain, lower limb (feet, knee, legs, hips) pain, or back pain during the last 12 months. Musculoskeletal symptoms were considered not present when workers had none of the three musculoskeletal problems (pain in neck and upper limb, lower limb, or back).

Statistical analysis

The characteristics of study participants (expressed in counts and proportions) were examined according to long working hours using chi-squared tests. To investigate the risk of musculoskeletal symptoms, a survey-weighted multiple logistic analysis was used. Other potential confounding variables—including age, sex, education level, income, shift work, and employment status—were adjusted in the model. Next, the relative excess risk due to interaction (RERI) and ratio of odds ratios (ORs) were estimated to perform the interaction analysis between long working hours and ergonomic risk factors. The ratio of ORs and 95% confidence interval (CI), which were calculated by the post-estimation commands "linear combination of coefficients" (lincom), estimated the combined effects based on multiplicative scales. The RERI and 95% CI, which were calculated by the post-estimation commands "nonlinear combination of coefficients" (nlcom), estimated the combined effects based on additive scale. Stata version 16.1 software was used for all statistical analyses, with a two-tailed statistical significance level of $p < 0.05$.

For an additive scale of the interaction between long working hours and ergonomic risk factor, RERI was estimated;

$$\text{RERI} = \text{OR}_{\text{combined exposure to long working hours and ergonomic factor}} - \text{OR}_{\text{exposure to only ergonomic factor}} - \text{OR}_{\text{exposure to only long working hours}} + 1$$

For a multiplicative scale of the interaction between long working hours and ergonomic risk factors, the ratio of ORs was estimated:

$$\text{OR}_{\text{combined exposure to long working hours and ergonomic factor}} / (\text{OR}_{\text{exposure to only ergonomic factor}} * \text{OR}_{\text{exposure to only long working hours}})$$

When the ratio of the ORs was greater than 1 or the RERI was greater than 0, exposure to simultaneous long working hours and ergonomic risk factors had a stronger effect on musculoskeletal symptoms than the sum or product of the expected values when each variable is exposed independently.

RESULTS

Of the 34,316 study participants (unweighted sample size = 27,927), 14,104 (41%) were female. We observed that 14.4% of Korean employees worked more than 52 hours per week (Table 1). Higher proportions of participants reporting long working hours were found among males (17%), older adults (24%), high school graduates (23%), and low–middle income (18%) workers. Regarding work-related variables, workers with temporary jobs

(20%) and shift work (23%) had the highest percentage of long working hours. In addition, workers who were exposed to ergonomic risk factors were more likely to report long working hours.

Table 1. Characteristics of study population

	Total		Long working hours (−)[a]		Long working hours (+)[b]		
	n	Proportion	*n*	Proportion	*n*	Proportion	*p*-value *
Gender	34316						<0.001
Male	20212	0.59	16730	0.83	3482	0.17	
Female	14104	0.41	12636	0.90	1468	0.10	
Age							<0.001
15–29	6233	0.18	5319	0.85	913	0.15	
30–39	8874	0.26	7846	0.88	1028	0.12	
40–49	9025	0.26	7870	0.87	1154	0.13	
50–59	7084	0.21	5963	0.84	1120	0.16	
≥60	3101	0.09	2367	0.76	734	0.24	
Education							<0.001
Middle school or less	2265	0.06	1178	0.79	487	0.21	

High school	10534	0.31	8115	0.77	8119	0.23	
College or more	21493	0.63	19450	0.90	2043	0.10	
Employment							<0.001
Regular	29375	0.86	25362	0.86	4012	0.14	
Temporary	3524	0.10	2822	0.80	701	0.20	
Daily	1418	0.04	1182	0.83	237	0.17	
Income							<0.001
Lowest	5060	0.16	4449	0.88	611	0.12	
Low–middle	7970	0.25	6555	0.82	1415	0.18	
High–middle	9365	0.29	7838	0.84	1528	0.16	
Highest	9826	0.30	8688	0.88	1138	0.12	
Shift work							<0.001
No	30236	0.88	26221	0.89	4014	0.81	
Yes	4073	0.12	3144	0.11	928	0.19	
Ergonomic risk factors							<0.001
Risk factors (−)	8775	0.26	8069	0.27	707	0.14	

Risk factors (+)	25533	0.74	21292	0.73	4241	0.86

[a]Long working hours (−): ≤ 30 and ≤52 hours

[b]Long working hours (+): > 52 hours

*Estimated by survey-weighted χ^2 test

Table 2 shows the relationship between independent variables and musculoskeletal symptoms. Ergonomic risk factors (OR = 3.37; 95% CI = 2.99–3.80), long working hours (OR = 1.51, 95% CI = 1.36–1.67), female workers (OR = 1.21, 95% CI = 1.11–1.32), and shift workers (OR = 1.29, 95% CI = 1.15–1.44) were more likely to report musculoskeletal symptoms. Compared with regular workers, temporary workers were less likely (OR = 0.82, 95% CI = 0.73–0.93) and daily workers were more likely to experience musculoskeletal symptoms (OR = 2.13, 95% CI = 1.81–2.49). Regarding education level, workers with middle school graduation or less (OR = 3.10, 95% CI = 2.65–3.63) and those with high school graduation (OR = 1.86, 95% CI = 1.69–2.04) had a higher risk of musculoskeletal symptoms than college graduates or more. However, there was no statistically significant association between income and musculoskeletal symptoms.

Table 2. Factors associated with musculoskeletal symptoms by survey-weighted multiple logistic analysis

	Odds ratio	95% Confidence interval	*p*-value
Weekly working hours			
30–52	Reference		

>52	1.51	1.36	1.67	<0.001
Ergonomic risk factor				
Risk factor (-)	ref			
Risk factor (+)	3.37	2.99	3.80	<0.001
Employment				
Regular	Reference			
Temporary	0.82	0.73	0.93	<0.001
Daily	2.13	1.81	2.49	<0.001
Shift work				
No	Reference			
Yes	1.29	1.15	1.44	<0.001
Income				
Highest	Reference			
High–middle	1.02	0.89	1.18	0.735
Low–middle	1.04	0.92	1.18	0.533
Lowest	1.07	0.96	1.19	0.244
Education				
College or more	Reference			
High school	1.86	1.69	2.04	<0.001
Middle school or less	3.10	2.65	3.63	<0.001
Gender				
Male	Reference			
Female	1.21	1.11	1.32	< 0.001

Age				
15–29	Reference			
30–39	1.88	1.60	2.21	<0.001
40–49	2.31	1.98	2.69	<0.001
40–59	2.55	2.19	2.98	<0.001
≥60	2.18	1.82	2.61	<0.001

ORs: odds ratios; CI: confidence interval

Table 3 shows the effect of the interaction between long working hours and ergonomic risk factors on musculoskeletal symptoms. For long working hours without ergonomic risk factors, the OR for musculoskeletal symptoms was 1.75 (95 % CI = 1.28–1.39). For ergonomic risk factors without long working hours, the OR of musculoskeletal symptoms was 3.49 (95% CI = 3.06–3.99). In addition, if workers were exposed to simultaneous long working hours and ergonomic risk factors, the OR for musculoskeletal symptoms was 5.07 (95% CI = 4.33–5.93). The RERI was 0.82 (95% CI = 0.11–1.53), and the ratio of ORs was 0.83 (95% CI = 0.50–1.14). Thus, we observed a supra-additive interaction between long working hours and ergonomic risk factors regarding their effect on musculoskeletal symptoms.

Table 3. Interaction effect of long working hours and ergonomic risk factors on musculoskeletal symptoms

	Long working hours (−)[a]	Long working hours (+)[b]	OR for long working hours (−)[a]

	OR (95% CI): *P*	OR (95% CI): *P*	vs. long working hours (+)[b] within strata of ergonomic risk factor OR (95% CI): *P*
Ergonomic risk factors (-)	Reference	1.75 (1.28–2.39): <0.001	1.75 (1.28–2.39): <0.001
Ergonomic risk factors (+)	3.49 (3.06–3.99): <0.001	5.07 (4.33–5.93): <0.001	1.45 (1.30–1.61): <0.000
OR for ergonomic risk factors (-) vs. ergonomic risk factors (+) within strata of long working hours	3.49 (3.06–3.99): <0.001	2.89 (2.14–3.90): <0.001	
Measure of interaction on additive scale: RERI	0.82 (0.11–1.53): 0.024		
Measure of interaction	0.83 (0.50–1.14): 0.256		

on multiplicative scale: ratio of ORs	

[a]Long working hours (−): ≤30 and ≤52 hours; [b]Long working hours (+): >52 hours; OR: odds ratio; CI: confidence interval; RERI: relative excess risk due to interaction. Age, sex, education, income, employment, and shift work were adjusted for in the model.

DISCUSSION

The results of the current study showed that long working hours and ergonomic risk factors are associated with musculoskeletal symptoms. These results share similarities with previous studies showing that long working hours increased the risk of back pain and the diagnosis of neck and shoulder disorders, and that ergonomic risk factors such as heavy physical work, lifting movements, and awkward postures can increase the risk of lower back pain.[4, 13–17] Furthermore, repetitive work was also found to be associated with musculoskeletal disorders of the neck, shoulder, hand, and wrist.[4, 18–20]

There was a synergy between long working hours and ergonomic risk factors on musculoskeletal symptoms. To the best of our knowledge, there have been few studies analyzing the combined effect of ergonomic risk factors and long working hours via interaction analysis, on both additive and multiplicative scales. The most appropriate method is to report interactions by using both scales.[21, 22] Therefore, in this study, RERI (an additive scale) and ratio of ORs (a multiplicative scale) were calculated to conduct an interaction analysis. Although no statistical significance was observed on the multiplicative scale, RERI was greater than 0, which indicates the supra-additive interaction between long working hours and ergonomic risk factors. We observed a synergistic effect of the co-exposure to long work hours and ergonomic risk factors on musculoskeletal symptoms that was more detrimental than a simple addition of harmful effects by each exposure. As long working hours imply prolonged exposure to ergonomic risk factors (e.g., repetitive tasks, heavy lifting, and uncomfortable posture) and insufficient recovery, the interaction of long working hours and ergonomic risk factors can lead to a higher risk of musculoskeletal symptoms, compared with their simple additive effect. Several studies have suggested a dose-response relationship between co-existing ergonomic risk factors, such as workload, lifting, and awkward posture.[23–25] However, the results of this study suggest that the supra-additive interaction between long working hours and ergonomic risk factors can worsen the problem.

The current study proposed that stricter regulation of working hours is required. In 2018, concerns over the long working hours of Korean workers led the government to limit the legal working hours to 52 hours or fewer per week. However, regulations on working hours are not strict and are applied only to large enterprises with 300 or more employees.[26] This means that employees in small-scale workplaces have a higher risk of working long hours.[27] In addition, it is well known that employees in small-scale workplaces work under unfavorable conditions more often than those in large-scale workplaces. The implementation of legal systems prohibiting long working hours, especially more than 52 hours, may help to reduce the prevalence of musculoskeletal symptoms, particularly among workers in small-scale workplaces. Moreover, working conditions should be improved. As such, multifocal ergonomic interventions programs, such as training in ergonomic principles, workstation modification (modifying working postures), surveying ergonomics, and exercise programs, are recommended to reduce musculoskeletal symptoms and the risk of developing musculoskeletal disorders.[28–31]

This study had several limitations. First, it was a cross-sectional study; therefore, causality between exposure and musculoskeletal disorders could not be established because of the nature of the study design. However, when employees have musculoskeletal pain, they could not extend their working hours, owing to their symptoms. Therefore, the possibility of a reverse causal relationship between long working hours and musculoskeletal symptoms is low. Second, the assessment of working hours and musculoskeletal symptoms was self-reported, which can lead to information bias. Third, this study did not consider other possible confounders, such as past medical history of injury, exercise, and body mass index, which could affect musculoskeletal symptoms. Fourth, we assessed musculoskeletal symptoms instead of musculoskeletal disorders. However, musculoskeletal symptoms are highly correlated with physical findings of musculoskeletal disorders as well as accompanying or preceding musculoskeletal diseases.[32, 33] Therefore, to prevent the occurrence of work-related musculoskeletal disorders, it makes sense to investigate the musculoskeletal symptoms in the workplace.

In conclusion, the findings of this study suggest that long working hours combined with ergonomic risk factors can have harmful synergistic effects on musculoskeletal symptoms. The health of workers whom experience unfavorable working conditions, especially those concurrently exposed to ergonomic risk factors and long working hours, could be improved by reduced working hours and ergonomic improvement. Strict regulation of working hours and ergonomic intervention programs could help to prevent musculoskeletal disease in the workplace.

Acknowledgments

The authors sincerely appreciate the support of the Occupational Safety and Health Research Institute (OSHRI) and the KOSHA for providing us with the raw data from the fifth KWCS. This research is an important part of a thesis for a Master's degree of Jeong Woo Park from the Graduate School of Dong-A University.

Data Availability

Data are available in a public, open access repository KOSHA (https://www.kosha.or.kr/kosha/data/primitiveData.do)

Authors' Contributions

Seong-Sik Cho: Conceptualization, formal analysis, methodology, writing—original draft, writing—review & editing; **Jeong-Woo Park**: Writing—original draft, Writing—review & editing; **Mo-Yeol Kang**: Writing—original draft **Jung-Il Kim**: Writing—review & editing; **Jong-Hyun Hwang**: Writing—review & editing. All authors have read and agreed to the published version of the manuscript.

Funding Statement

This research is supported by the Dong-a University Research Fund [Grant Number: NA]. The funding body had no role to play in the study design, the collection, analysis and interpretation of the data, the writing of the report, and the decision to submit the paper for

publication.

Competing Interests Statement

The authors declare no conflicts of interest.

Ethics Approval Statement: The written informed consent and the review of the study was waived by the Institutional Review Board of Dong-A University Hospital (Approval No: DAUHIRB-TEMP-20-212).

REFERENCES

1 Punnett L, Wegman DH. Work-related musculoskeletal disorders: the epidemiologic evidence and the debate. *J Electromyogr Kinesiol* 2004;14:13–23.

2 Morken T, Riise T, Moen B, et al. Low back pain and widespread pain predict sickness absence among industrial workers. *BMC Musculoskelet Disord* 2003;4:21.

3 Ministry of Employment and Labor. Yearbooks of industrial accident. http://kosha.or.kr/kosha/data/industrialAccidentStatus.do?mode=view&articleNo=410303&article.offset=0&articleLimit=10 (Accessed 10 Nov 2020).

4 Putz-Anderson V, Bernard B, Burt S, et al. Musculoskeletal disorders and workplace factors: A critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck, upper extremity, and low back. Cincinnati: NIOSH Publ., 97–141 1997.

5 Bergsten EL, Mathiassen SE, Vingård E. Psychosocial work factors and musculoskeletal pain: a cross-sectional study among Swedish flight baggage handlers. *BioMed Res Int* 2015;2015:798042.

6 Amin NA, Nordin R, Fatt QK, et al. Relationship between psychosocial risk factors and work-related musculoskeletal disorders among public hospital nurses in Malaysia. *Ann Occup Environ Med* 2014;26:23.

7 Virtanen M, Heikkilä K, Jokela M, et al. Long working hours and coronary heart disease: A systematic review and meta-analysis. *Am J Epidemiol* 2012;176:586–96.

8 Kivimäki M, Jokela M, Nyberg ST, et al. Long working hours and risk of coronary heart disease and stroke: a systematic review and meta-analysis of published and unpublished data for 603,838 individuals. *Lancet* 2015;386:1739–46.

9 Dembe AE, Erickson JB, Delbos RG, et al. The impact of overtime and long work hours on occupational injuries and illnesses: new evidence from the United States. *Occup Environ Med* 2005;62:588–97.

10 Amagasa T, Nakayama T. Relationship between long working hours and depression: A 3-year longitudinal study of clerical workers. *J Occup Environ Med* 2013;55:863–72.

11 Virtanen M, Ferrie JE, Singh-Manoux A, et al. Long working hours and symptoms of anxiety and depression: A 5-year follow-up of the Whitehall II study. *Psychol Med* 2011;41:2485–94.

12 OECD statistics. Organization for economic co-operation and development. Average usual weekly hours worked on the main job. https://stats.oecd.org/Index.aspx?DataSetCode=AVE_HRS (Accessed 3 Nov 2017).

13 Trinkoff AM, Le R, Geiger-Brown J, et al. Longitudinal relationship of work hours, mandatory overtime, and on-call to musculoskeletal problems in nurses. *Am J Ind Med* 2006;49:964–71.

14 Johansson JA, Rubenowitz S. Risk indicators in the psychosocial and physical work environment for work-related neck, shoulder and low back symptoms: a study among blue- and white-collar workers in eight companies. *Scand J Rehabil Med* 1994;26:131–42.

15 Burdorf A, Zondervan H. An epidemiological study of low-back pain in crane operators. *Ergonomics* 1990;33:981–7.

16 Burdorf A, Govaert G, Elders L. Postural load and back pain of workers in the manufacturing of prefabricated concrete elements. *Ergonomics* 1991;34:909–18.

17 Punnett L, Fine LJ, Keyserling WM, et al. Back disorders and nonneutral trunk postures

of automobile assembly workers. *Scand J Work Environ Health* 1991;17:337–46.

18 Bergqvist U, Wolgast E, Nilsson B, et al. Musculoskeletal disorders among visual display terminal workers: Individual, ergonomic, and work organizational factors. *Ergonomics* 1995;38:763–76.

19 Chiang HC, Ko YC, Chen SS, et al. Prevalence of shoulder and upper-limb disorders among workers in the fish-processing industry. *Scand J Work Environ Health* 1993;19:126–31.

20 Silverstein BA, Fine LJ, Armstrong TJ. Occupational factors and carpal tunnel syndrome. *Am J Ind Med* 1987;11:343–58.

21 Van der Weele TJ, Knol MJ. A tutorial on interaction. *Epidemiol Meth* 2014;3:33–72.

22 Rothman KJ, Greenland S, Walker AM. Concepts of interaction. *Am J Epidemiol* 1980;112:467–70.

23 Videman T, Nurminen T, Tola S, et al. Low-back pain in nurses and some loading factors of work. *Spine (Phila Pa 1976)* 1984;9:400–4.

24 Marras WS, Lavender SA, Leurgans SE, et al. Biomechanical risk factors for occupationally related low back disorders. *Ergonomics* 1995;38:377–410.

25 Riihimäki H, Tola S, Videman T, et al. Low-back pain and occupation. A cross-sectional questionnaire study of men in machine operating, dynamic physical work, and sedentary work. *Spine (Phila Pa 1976)* 1989;14:204–9.

26 Ministry of Government Legislation. Labor Standards Act. *Laws on Green Growth, and Economic Investment in Korea*. https://www.law.go.kr/LSW/eng/engLsSc.do?menuld=2&secTion=lawNm&query=Labor+Standards+Act&x=0&y=0#liBgcolor0 (Accessed 26 May 2020).

27 Jeong MJ. Analysis on the actual conditions of safety management about small sized enterprises—Focused on to small enterprises in Kyunggi area. *J Korea Saf Manag Sci* 2007;9;47–54.

28 Szeto GPY, Wong TKT, Law RKY, et al. The impact of a multifaceted ergonomic intervention program on promoting occupational health in community nurses. *Appl Ergon* 2013;44:414–22.

29 Aghilinejad M, Bahrami-Ahmadi A, Kabir-Mokamelkhah E, et al. The effect of three ergonomics training programs on the prevalence of low-back pain among workers of an Iranian automobile factory: a randomized clinical trial. *Int J Occup Environ Med* 2014;5:65–71.

30 Aghilinejad M, Kabir-Mokamelkhah E, Labbafinejad Y, et al. The role of ergonomic training interventions on decreasing neck and shoulders pain among workers of an Iranian automobile factory: A randomized trial study. *Med J Islam Repub Iran* 2015;29:190.

31 Hignett S. Intervention strategies to reduce musculoskeletal injuries associated with handling patients: A systematic review. *Occup Environ Med* 2003;60:E6.

32 Baron SL, Hales TR, Hurrell J. Evaluation of symptom surveys for occupational musculoskeletal disorders. *Am J Ind Med* 1996;29:609–17.

33 Hünting W, Läubli T, Grandjean E. Postural and visual loads at VDT workplaces. I. Constrained postures. *Ergonomics* 1981;24:917–31.

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4
Objectives	3	State specific objectives, including any prespecified hypotheses	4
Methods			
Study design	4	Present key elements of study design early in the paper	5
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	5
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	NA
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6,7
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	6,7
Bias	9	Describe any efforts to address potential sources of bias	6,7
Study size	10	Explain how the study size was arrived at	6,7
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	6,7
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	7,8
		(*b*) Describe any methods used to examine subgroups and interactions	7,8
		(*c*) Explain how missing data were addressed	NA
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy	7,8
		(*e*) Describe any sensitivity analyses	NA

Continued on next page

Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	8
		(b) Give reasons for non-participation at each stage	8
		(c) Consider use of a flow diagram	NA
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	8-10
		(b) Indicate number of participants with missing data for each variable of interest	8-10
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	NA
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	NA
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	NA
		Cross-sectional study—Report numbers of outcome events or summary measures	10-14
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	10-14
		(*b*) Report category boundaries when continuous variables were categorized	10-14
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	10-14
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	NA
Discussion			
Key results	18	Summarise key results with reference to study objectives	14,15
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	16
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	14,15
Generalisability	21	Discuss the generalisability (external validity) of the study results	16
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	18

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

BMJ Open

Influence of co-exposure to long working hours and ergonomic risk factors on musculoskeletal symptoms: An interaction analysis

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2021-055186.R1
Article Type:	Original research
Date Submitted by the Author:	21-Jan-2022
Complete List of Authors:	Park, Jeongwoo; Dong-A University College of Medicine, Kang, Mo-Yeol ; Catholic University of Korea College of Medicine, Occupational and environment meidcine Kim, Jung Il; Dong-A University College of Medicine, Department of Occupational & Environmental Medicine Hwang, Jong-Hyun ; Dong-A University College of Medicine, Occupational and environmental medicine Choi, Seong-Soo; University of Ulsan College of Medicine, Cho, Seong-Sik; Dong-A University, Department of Occupational and Environmental Medicine
Primary Subject Heading:	Occupational and environmental medicine
Secondary Subject Heading:	Epidemiology
Keywords:	EPIDEMIOLOGY, OCCUPATIONAL & INDUSTRIAL MEDICINE, Musculoskeletal disorders < ORTHOPAEDIC & TRAUMA SURGERY

SCHOLARONE™
Manuscripts

BMJ

Influence of co-exposure to long working hours and ergonomic risk factors on musculoskeletal symptoms: An interaction analysis

Jeong-Woo Park, MD[1]; Mo-Yeol Kang, MD[2]; Jung-Il Kim, MD[1]; Jong-Hyun Hwang, MD[3]; Seong-Soo Choi[4], Seong-Sik Cho, MD[1]*

[1]Department of Occupational and Environmental Medicine, College of Medicine, Dong-A University, Busan, Korea

[2]Department of Occupational and Environmental Medicine, Seoul St. Mary's Hospital, College of Medicine, The Catholic University of Korea, Seoul, Korea

[3]Department of Occupational and Environmental Medicine, Dong-A University hospital, Busan, Korea

[4]Department of Anesthesiology and Pain Medicine, Asan Medical Center, University of Ulsan College of Medicine

***Corresponding Author**: Seong-Sik Cho

Department of Occupational and Environmental Medicine, College of Medicine

Dong-A University

32 Daesingongwon-ro, Seo-gu, Busan 49201, Korea

Phone: 82 10-4920-9725

Fax: 051-242-8428

Email: sscho@dau.ac.kr

Word Count (excluding title page, abstract, references, figures and tables): 2632words

Objectives

This study explores the interaction between ergonomic risk factors and long working hours on musculoskeletal symptoms by additive and multiplicative scales.

Design

We used the data of the fifth Korean working condition survey (KWCD). The KWCD is a cross-sectional study.

Setting

To represent the entire Korean working population, the probability proportion stratified cluster sampling method was used. The face-to-face interview was carried out with a structured questionnaire.

Main outcomes and measures

To assess the combined effect of ergonomic risk factors and long working hours on musculoskeletal symptoms, the relative excess risk due to interaction (RERI) and the ratio of odds ratios (ORs) were calculated using multiple survey-weighted logistic analysis and post-estimation commands

Results

The OR for musculoskeletal symptoms was 1.75 (95% confidence interval [CI] = 1.28–1.39) for exposure to long working hours, 3.49 (95% CI = 3.06–3.99) for exposure to ergonomic risk factors, and 5.07 (95% CI = 4.33–5.93) for co-exposure to long working hours and ergonomic risk factors. The RERI was 0.82 (95% CI = 0.11–1.53), and the ratio of ORs was 0.83 (95% CI = 0.50–1.14)

Conclusion

Our findings suggest that co-exposure to both ergonomic risk factors and long working hours

has a supra-additive interaction effect on musculoskeletal symptoms

Strength & Limitation of this study

This study analyzed a nationally representative sample (the KWCS) with a large sample size (34,316).

This study conducted interaction analysis in both additive and multiplicative scales.

The causality between exposures and musculoskeletal disorders could not be established due to the nature of the study design (a cross-sectional study).

Self-reporting of working hours and musculoskeletal symptoms may lead to information bias.

The potential confounders, such as body mass index, previous history of musculoskeletal diseases, were not assessed in this study.

INTRODUCTION

Musculoskeletal disorders are an important work-related health issue worldwide, as they increase medical costs due to their high prevalence.[1] Work-related musculoskeletal disorders account for 40% of all work-related medical expenses worldwide.[2] In South Korea, they accounted for 57.6% of all work-related diseases in 2018.[3] A variety of risk factors, including physical and psychosocial factors, are associated with musculoskeletal disorders. Ergonomic risk factors, such as awkward or painful posture, heavy physical workload, lifting and forceful movements, and repetitive hand or arm movements, are well-known risk factors of musculoskeletal disorders.[4] Moreover, an increased risk of developing work-related musculoskeletal disorders is linked to psychosocial factors, including poor job control and low social support.[5, 6]

Long working hours can be harmful to workers' health and well-being, and are linked to physical health problems such as atrial fibrillation, coronary heart disease, stroke, occupational injury, depression, and suicidal ideation.[7–11] The Korean government has acknowledged the adverse effects of excessive working hours and has legally stipulated a maximum of 52 working hours per week. However, the average annual working hours of Korea were still 1,967 hours in 2019, which is 241 more hours than in OECD countries.[12]

Long working hours imply that workers in a hazardous working environment are exposed to risks for longer periods. Thus, co-exposure to long working hours combined with other occupational risk factors could be more harmful. From this perspective, co-exposure to long working hours and ergonomic risk factors may lead to a higher prevalence of musculoskeletal disorders in the workplace. However, few studies have reported the combined effect of long working hours and ergonomic risk factors on musculoskeletal

disorders, particularly using both additive and multiplicative scales. Thus, this study aimed to identify the combined effect of long working hours and ergonomic risk factors on musculoskeletal symptoms by interaction analysis on both additive and multiplicative scales.

METHODS

Study participants

We used a data sample from the fifth Korean Working Condition Survey (KWCS), conducted by the Korea Occupational Safety and Health Agency (KOSHA). The KWCS is comparable to the European Working Conditions Survey; it aims to survey the working conditions in various occupations. The sample from the fifth KWCS was recruited from 17 cities and provinces in Korea and excludes individuals younger than 15 years.

The target population included nationwide employed individuals aged 15 years or older in all Korean households in 2017. The survey was conducted through face-to-face interviews after obtaining consent from the participants. Students, stay-at-home spouses, unemployed, and retired individuals were excluded to ensure that the sample represented the economically active population. A sample design was constructed using a secondary probability proportion stratified cluster sample survey. Census districts were chosen based on the number of households. Thereafter, in each selected census district, ten households were randomly selected. Finally, one randomly selected eligible person in each household was interviewed (eligible persons were individuals employed at the point of the survey). The data of the fifth KWCS used design-weight to adjust the non-response rate and sample selection. In addition, the raking ratio method was used for post-stratification to adjust for the characteristics of gender, age, region, locality, and occupation.

Of the total 50,205 employees (unweighted sample size = 50,205), 34,316 wage workers (unweighted sample size = 27,927)—excluding self-employed, unpaid family workers, and employers—were included in the analysis. Only employees whose weekly working hours totaled more than 30 hours were included to exclude the impact of incomplete employment.

Patient and public involvement

Participants in the study were not involved in the design of the study. The raw data of KWCS is available to the public. The study findings were only published in peer-reviewed journals, with no other information about the results provided to participants.

Ethical considerations

The data used in our study are the fifth Korean working condition survey which is open to the public with personally identifiable information deleted. The need for written informed consent was waived off, and this study was approved by the Institutional Review Board of Dong-A University Hospital (Approval No: DAUHIRB-TEMP-20-212).

Study variables

All study variables were collected from the KWCS questionnaire. Sociodemographic variables included gender, age, educational level, and income. Age was divided into five categories: <30, 30–39, 40–49, 50–59, ≥60. Education was classified according to three levels: middle school or less, high school graduate, or college or more. Monthly income was categorized into quartiles. Employment status was classified into three categories: regular, temporary, and daily. Shift work was classified into two categories (yes or no). The information about working hours per week was collected using the following question: "How many hours do you work per week?" Answers were divided into two categories: 30–52 h/week was classed as "standard working hours," while more than 52 h/week was classed as "long working hours."

Exposure to ergonomic risk factors was assessed using a questionnaire. First, the percentage of time that workers were exposed to a specific motion or posture during their working time was recorded. There were five items assessing ergonomic risk factors, namely tiring or painful position, lifting or moving people, carrying or moving heavy loads, continuous standing, and repetitive hand or arm movements.[4] For each item, the results were dichotomized into "with exposure" when the exposure time was half of the working hours or more per day, or "without exposure" when the exposure time was less than half of the working hours per day. Finally, if any of the five items were reported as "with exposure," "ergonomic risk factor" was considered present, while if all five items were reported as "without exposure," "ergonomic risk factor" was considered not present.

Musculoskeletal symptoms were present when workers had any of the three following symptoms: neck and upper limb (shoulder, arm, elbow, wrist, hand) pain, lower limb (feet, knee, legs, hips) pain, or back pain during the last 12 months. Musculoskeletal symptoms were considered not present when workers had none of the three musculoskeletal problems (pain in neck and upper limb, lower limb, or back).

Statistical analysis

The characteristics of study participants (expressed in counts and proportions) were demonstrated according to long working hours by using chi-squared tests. To investigate the risk of musculoskeletal symptoms, a survey-weighted multiple logistic analysis was used. Other potential confounding variables—including age, sex, education level, income, shift work, and employment status—were adjusted in the model. Also, by the weekly working hours and exposure to ergonomic risk factors OR ratios for musculoskeletal symptoms were estimated. Finally, the relative excess risk due to interaction (RERI) and ratio of odds ratios (ORs) were estimated to perform the interaction analysis between long working hours and ergonomic risk factors. The ratio of ORs and 95% confidence interval (CI), which were calculated by the post-estimation commands "linear combination of coefficients" (lincom), estimated the combined effects based on multiplicative scales. The RERI and 95% CI, which were calculated by the post-estimation commands "nonlinear combination of coefficients" (nlcom), estimated the combined effects based on additive scale. Stata version 16.1 software was used for all statistical analyses, with a two-tailed statistical significance level of $p < 0.05$.

For an additive scale of the interaction between long working hours and ergonomic risk factor, RERI was estimated;

$$RERI = OR_{\text{combined exposure to long working hours and ergonomic factor}} - OR_{\text{exposure to only ergonomic factor}} - OR_{\text{exposure to only long working hours}} + 1$$

For a multiplicative scale of the interaction between long working hours and ergonomic risk factors, the ratio of ORs was estimated:

$$OR_{\text{combined exposure to long working hours and ergonomic factor}} / (OR_{\text{exposure to only ergonomic factor}} * OR_{\text{exposure to only long working hours}})$$

In the epidemiologic study, if the RERI was greater than 0, it indicates there is a supra-additive interaction of two concurrent exposures. If the estimated ratio of the ORs was greater than 1, it indicates there is a supra-multiplicate interaction of two simultaneous exposures.[13]

RESULTS

Of the 34,316 study participants (unweighted sample size = 27,927), 14,104 (41%) were female. We observed that 14.4% of Korean employees worked more than 52 hours per week (Table 1). Higher proportions of participants reporting long working hours were found among males (17%), older adults (24%), high school graduates (23%), and low–middle income (18%) workers. Regarding work-related variables, workers with temporary jobs (20%) and shift work (23%) had the highest percentage of long working hours. In addition, workers who were exposed to ergonomic risk factors were more likely to report long working hours.

Table 1. Characteristics of study population

	Total		Long working hours (−)[a]		Long working hours (+)[b]		
	n	Proportion	*n*	Proportion	*n*	Proportion	*p*-value *
Gender	34316						<0.001
Male	20212	0.59	16730	0.83	3482	0.17	
Female	14104	0.41	12636	0.90	1468	0.10	

Age							<0.001
15–29	6233	0.18	5319	0.85	913	0.15	
30–39	8874	0.26	7846	0.88	1028	0.12	
40–49	9025	0.26	7870	0.87	1154	0.13	
50–59	7084	0.21	5963	0.84	1120	0.16	
≥60	3101	0.09	2367	0.76	734	0.24	
Education							<0.001
Middle school or less	2265	0.06	1178	0.79	487	0.21	
High school	10534	0.31	8115	0.77	8119	0.23	
College or more	21493	0.63	19450	0.90	2043	0.10	
Employment							<0.001
Regular	29375	0.86	25362	0.86	4012	0.14	
Temporary	3524	0.10	2822	0.80	701	0.20	
Daily	1418	0.04	1182	0.83	237	0.17	
Income							<0.001
Lowest	5060	0.16	4449	0.88	611	0.12	
Low–middle	7970	0.25	6555	0.82	1415	0.18	
High–middle	9365	0.29	7838	0.84	1528	0.16	

Highest	9826	0.30	8688	0.88	1138	0.12	
Shift work							<0.001
No	30236	0.88	26221	0.87	4014	0.13	
Yes	4073	0.12	3144	0.77	928	0.23	
Ergonomic risk factors							<0.001
Risk factors (−)	8775	0.26	8069	0.92	707	0.08	
Risk factors (+)	25533	0.74	21292	0.83	4241	0.17	

[a]Long working hours (−): ≤ 30 and ≤52 hours

[b]Long working hours (+): > 52 hours

*Estimated by survey-weighted χ^2 test

Table 2 shows the relationship between independent variables and musculoskeletal symptoms. Ergonomic risk factors (OR = 3.37; 95% CI = 2.99–3.80), long working hours (OR = 1.51, 95% CI = 1.36–1.67), female workers (OR = 1.21, 95% CI = 1.11–1.32), and shift workers (OR = 1.29, 95% CI = 1.15–1.44) were more likely to report musculoskeletal symptoms. Compared with regular workers, temporary workers were less likely (OR = 0.82, 95% CI = 0.73–0.93) and daily workers were more likely to experience musculoskeletal symptoms (OR = 2.13, 95% CI = 1.81–2.49). Regarding education level, workers with middle school graduation or less (OR = 3.10, 95% CI = 2.65–3.63) and those with high school graduation (OR = 1.86, 95% CI = 1.69–2.04) had a higher risk of musculoskeletal symptoms than college graduates or more. However, there was no statistically significant association between income and musculoskeletal symptoms.

Table 2. Factors associated with musculoskeletal symptoms by survey-weighted multiple logistic analysis (population size=32,184)

	Odds ratio	95% Confidence interval		*p*-value
Weekly working hours				
30–52	Reference			
>52	1.51	1.36	1.67	<0.001
Ergonomic risk factor				
Risk factor (-)	Reference			
Risk factor (+)	3.37	2.99	3.80	<0.001
Employment				
Regular	Reference			
Temporary	0.82	0.73	0.93	<0.001
Daily	2.13	1.81	2.49	<0.001
Shift work				
No	Reference			
Yes	1.29	1.15	1.44	<0.001
Income				
Highest	Reference			
High–middle	1.02	0.89	1.18	0.735
Low–middle	1.04	0.92	1.18	0.533

Lowest	1.07	0.96	1.19	0.244
Education				
College or more	Reference			
High school	1.86	1.69	2.04	<0.001
Middle school or less	3.10	2.65	3.63	<0.001
Gender				
Male	Reference			
Female	1.21	1.11	1.32	< 0.001
Age				
15–29	Reference			
30–39	1.88	1.60	2.21	<0.001
40–49	2.31	1.98	2.69	<0.001
40–59	2.55	2.19	2.98	<0.001
≥60	2.18	1.82	2.61	<0.001

ORs: odds ratios; CI: confidence interval

musculoskeletal symptoms.

The effects of weekly work hours and ergonomic risk factors on musculoskeletal symptoms are shown in Table 3 and supplementary figure 1. Regardless of working hours, ergonomic risk factors increased the risk of musculoskeletal symptoms. For musculoskeletal symptoms, working hours had a U-shaped exposure-response curve. The OR (2.51, 95 percent confidence interval: 1.39-4.52) was lowest for workers with standard work hours (36-40) who were exposed to ergonomic risk factors. Additionally, when working hours exceeded the standard working hours, the risk of musculoskeletal symptoms gradually increased among workers exposed to ergonomic risk factors. The odds ratio (OR) was highest (5.01, 95 percent CI: 2.97-8.45) among employees with ergonomic risk factors and more than 60 weekly work hours.

Table 3. Association weekly working hours and musculoskeletal symptoms by ergonomic risk factors

	Ergonomic risk factors (-)				Ergonomic risk factors (+)			
	Odds ratio	95% CI		p	Odds ratio	95% CI		p
Weekly working hours								
30-35 hours	Reference				3.16	1.89	5.28	<0.001
36-40 hours	1.14	0.37	3.51	0.826	2.51	1.39	4.52	0.002
41-45 hours	0.90	0.54	1.50	0.677	3.01	1.84	4.92	<0.001
46-50 hours	1.28	0.73	2.25	0.385	4.35	2.65	7.15	<0.001
51-55 hours	1.31	0.62	2.77	0.482	4.86	2.88	8.22	<0.001
56-60 hours	2.13	1.15	3.96	0.017	4.90	2.95	8.14	<0.001
61- hours	1.31	0.61	2.83	0.490	5.01	2.97	8.45	<0.001

Survey weighted multiple logistic regression was employed, and age, sex, education, income, employment, and shift work were adjusted in the model.

Table 4 and figure 1 show the effect of the interaction between long working hours and ergonomic risk factors on musculoskeletal symptoms. For long working hours without ergonomic risk factors, the OR for musculoskeletal symptoms was 1.75 (95 % CI = 1.28–1.39). For ergonomic risk factors without long working hours, the OR of musculoskeletal symptoms was 3.49 (95% CI = 3.06–3.99). In addition, if workers were exposed to simultaneous long working hours and ergonomic risk factors, the OR for musculoskeletal symptoms was 5.07 (95% CI = 4.33–5.93). The RERI was 0.82 (95% CI = 0.11–1.53), and the ratio of ORs was 0.83 (95% CI = 0.50–1.14). Thus, we observed a supra-additive interaction between long working hours and ergonomic risk factors regarding their effect on musculoskeletal symptoms

Supplementary tables demonstrate the interaction between long working hours and heavy load on back pain and between long working hours and painful position on neck and upper limb pains. RERI for long working hours and heavy load on back pain was 0.98 (95%CI: 0.06-1.90), and RERI for long working hours and painful position on neck and upper limb pains was 1.30 (95%CI: 0.53-2.06). This study observed supra-additive interactions between long working hours and heavy load on back pain and between long working hours and painful position on neck and upper limb pains.

Table 4. Interaction effect of long working hours and ergonomic risk factors on musculoskeletal symptoms

	Long working hours (−)[a] OR (95% CI): *P*	Long working hours (+)[b] OR (95% CI): *P*	OR for long working hours (−)[a] vs. long working hours (+)[b] within strata of ergonomic risk factor OR (95% CI): *P*
Ergonomic risk factors (-)	Reference	1.75 (1.28–2.39): <0.001	1.75 (1.28–2.39): <0.001
Ergonomic risk factors (+)	3.49 (3.06–3.99): <0.001	5.07 (4.33–5.93): <0.001	1.45 (1.30–1.61): <0.000
OR for ergonomic risk factors (-) vs. ergonomic risk factors (+) within strata of long working hours	3.49 (3.06–3.99): <0.001	2.89 (2.14–3.90): <0.001	
Measure of interaction on additive scale: RERI	0.82 (0.11–1.53): 0.024		
Measure of interaction on multiplicative scale: ratio of ORs	0.83 (0.50–1.14): 0.256		

[a]Long working hours (−): ≤30 and ≤52 hours; [b]Long working hours (+): >52 hours; OR: odds ratio; CI: confidence interval; RERI: relative excess risk due to interaction. Age, sex, education, income, employment, and shift work were adjusted for in the model.

DISCUSSION

The current study results showed that long working hours and ergonomic risk factors are associated with musculoskeletal symptoms. These results share similarities with previous studies showing that long working hours increased the risk of back pain and the diagnosis of neck and shoulder disorders, and that ergonomic risk factors such as heavy physical work, lifting movements, and awkward postures can increase the risk of lower back pain.[4, 14–18] Furthermore, repetitive work was also found to be associated with musculoskeletal disorders of the neck, shoulder, hand, and wrist.[4, 19–21]

There was a synergy between long working hours and ergonomic risk factors on musculoskeletal symptoms. To the best of our knowledge, few studies have analyzed the combined effect of ergonomic risk factors and long working hours via interaction analysis on both additive and multiplicative scales. The most appropriate method is to report interactions by using both scales.[22, 23] Therefore, in this study, RERI (an additive scale) and ratio of ORs (a multiplicative scale) were calculated to conduct an interaction analysis. Although no statistical significance was observed on the multiplicative scale, RERI was greater than 0, which indicates the supra-additive interaction between long working hours and ergonomic risk factors. We observed a synergistic effect of the co-exposure to long work hours and ergonomic risk factors on musculoskeletal symptoms that was more detrimental than a simple addition of harmful effects by each exposure. Similarly, supra-additive interactions was observed in long working hours and heavy load on back pain and long working hours and painful position on neck and upper limb. As long working hours imply prolonged exposure to ergonomic risk factors (e.g., repetitive tasks, heavy lifting, and uncomfortable posture) and insufficient recovery, the interaction of long working hours and ergonomic risk factors can lead to a higher risk of musculoskeletal symptoms, compared with their simple additive effect. Several studies have suggested a dose-response relationship between co-existing ergonomic risk factors, such as workload, lifting, and awkward posture.[24–26] However, the results of this study suggest that the supra-additive interaction between long working hours and ergonomic risk factors can worsen the problem.

The current study proposed that stricter regulation of working hours is required. In 2018, concerns over the long working hours of Korean workers led the government to limit the legal working hours to 52 hours or fewer per week. However, regulations on working hours are not strict and are applied only to large enterprises with 300 or more employees.[27] This means that employees in small-scale workplaces have a higher risk of working long hours.[28] In addition, it is well known that employees in small-scale workplaces work under unfavorable conditions more often than those in large-scale workplaces. Implementing legal systems prohibiting long working hours, especially more than 52 hours, may help reduce the prevalence of musculoskeletal symptoms, particularly among workers in small-scale workplaces. Moreover, working conditions should be improved. As such, multifocal ergonomic interventions programs, such as training in ergonomic principles, workstation modification (modifying working postures), surveying ergonomics, and exercise programs, are recommended to reduce musculoskeletal symptoms and the risk of developing musculoskeletal disorders.[29–32]

This study had several limitations. First, it was a cross-sectional study; therefore, causality between exposure and musculoskeletal disorders could not be established because of the nature of the study design. However, when employees have musculoskeletal pain, they could not extend their working hours, owing to their symptoms. Therefore, the possibility of a reverse causal relationship between long working hours and musculoskeletal symptoms is low. Second, the assessment of working hours and musculoskeletal symptoms was self-reported, which can lead to information bias. Third, this study did not consider other possible confounders, such as past medical history of injury, exercise, and body mass index, which could affect musculoskeletal symptoms. Fourth, we assessed musculoskeletal symptoms instead of musculoskeletal disorders. However, musculoskeletal symptoms are highly correlated with physical findings of musculoskeletal disorders as well as accompanying or preceding musculoskeletal diseases.[33, 34] Therefore, to prevent the occurrence of work-related musculoskeletal disorders, it makes sense to investigate the musculoskeletal symptoms in the workplace.

In conclusion, the findings of this study suggest that long working hours combined with ergonomic risk factors can have harmful synergistic effects on musculoskeletal symptoms. The health of workers who experience unfavorable working conditions, especially those concurrently exposed to ergonomic risk factors and long working hours, could be improved by reduced working hours and ergonomic improvement. Strict regulation of working hours and ergonomic intervention programs could be helpful to prevent musculoskeletal disease in the workplace.

Acknowledgments

The authors sincerely appreciate the support of the Occupational Safety and Health Research Institute (OSHRI) and the KOSHA for providing us with the raw data from the fifth KWCS. This research is an important part of a thesis for a Master's degree of Jeong Woo Park from the Graduate School of Dong-A University.

Data Availability

Data are available upon reasonable request.

Authors' Contributions

Jeong-Woo Park: Writing—original draft, Writing—review & editing; **Mo-Yeol Kang**: Writing—review& editing: **Jung-Il Kim**: Writing—review & editing; **Jong-Hyun Hwang**: Writing—review & editing; **Seong-Soo Choi:** Writing—review & editing; **Seong-Sik Cho:** Conceptualization, formal analysis, methodology, writing—original draft, writing—review & editing. All authors have read and agreed to the published version of the manuscript.

Funding

This research is supported by the Dong-a University Research Fund. Funding is used for the publication charge and English proofreading.

Competing Interests Statement

The authors declare no conflicts of interest.

Ethics Approval Statement: The written informed consent and the review of the study was waived by the Institutional Review Board of Dong-A University Hospital (Approval No: DAUHIRB-TEMP-20-212).

REFERENCES

1 Punnett L, Wegman DH. Work-related musculoskeletal disorders: the epidemiologic evidence and the debate. *J Electromyogr Kinesiol* 2004;14:13–23. doi: 10.1016/j.jelekin.2003.09.015.

2 Morken T, Riise T, Moen B, et al. Low back pain and widespread pain predict sickness absence among industrial workers. *BMC Musculoskelet Disord* 2003;4:21. doi: 10.1186/1471-2474-4-21.

3 Ministry of Employment and Labor. Yearbooks of industrial accident. http://kosha.or.kr/kosha/data/industrialAccidentStatus.do?mode=view&articleNo=410303&article.offset=0&articleLimit=10 (Accessed 10 Nov 2020).

4 Putz-Anderson V, Bernard B, Burt S, et al. Musculoskeletal disorders and workplace factors: A critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck, upper extremity, and low back. Cincinnati: NIOSH Publ., 97–141 1997.

5 Bergsten EL, Mathiassen SE, Vingård E. Psychosocial Work Factors and Musculoskeletal Pain: A Cross-Sectional Study among Swedish Flight Baggage Handlers. Biomed Res Int. 2015;2015:798042. doi:10.1155/2015/798042

6 Amin NA, Nordin R, Fatt QK, et al. Relationship between psychosocial risk factors and work-related musculoskeletal disorders among public hospital nurses in Malaysia. *Ann Occup Environ Med* 2014;26:23. doi:10.1186/s40557-014-0023-2

7 Virtanen M, Heikkilä K, Jokela M, et al. Long working hours and coronary heart disease: A systematic review and meta-analysis. *Am J Epidemiol* 2012;176:586–96. doi:10.1093/aje/kws139

8 Kivimäki M, Jokela M, Nyberg ST, et al. Long working hours and risk of coronary heart disease and stroke: a systematic review and meta-analysis of published and unpublished data for 603,838 individuals. *Lancet* 2015;386:1739–46. doi:10.1016/S0140-6736(15)60295-1

9 Dembe AE, Erickson JB, Delbos RG, et al. The impact of overtime and long work hours on occupational injuries and illnesses: new evidence from the United States. *Occup Environ Med* 2005;62:588–97. doi:10.1136/oem.2004.016667

10 Amagasa T, Nakayama T. Relationship between long working hours and depression: A 3-year longitudinal study of clerical workers. *J Occup Environ Med* 2013;55:863–72. doi:10.1097/JOM.0b013e31829b27fa

11 Virtanen M, Ferrie JE, Singh-Manoux A, et al. Long working hours and symptoms of anxiety and depression: A 5-year follow-up of the Whitehall II study. *Psychol Med* 2011;41:2485–94. doi:10.1017/S0033291711000171

12 OECD statistics. Organization for economic co-operation and development. Average usual weekly hours worked on the main job. https://stats.oecd.org/Index.aspx?DataSetCode=AVE_HRS (Accessed 3 Nov 2017).

13 Knol MJ, VanderWeele TJ. Recommendations for presenting analyses of effect modification and interaction. Int J Epidemiol. 2012;41(2):514-520. doi:10.1093/ije/dyr218

14 Trinkoff AM, Le R, Geiger-Brown J, et al. Longitudinal relationship of work hours, mandatory overtime, and on-call to musculoskeletal problems in nurses. *Am J Ind Med* 2006;49:964–71. doi:10.1002/ajim.20330

15 Johansson JA, Rubenowitz S. Risk indicators in the psychosocial and physical work

environment for work-related neck, shoulder and low back symptoms: a study among blue- and white-collar workers in eight companies. *Scand J Rehabil Med* 1994;26:131–42.

16 Burdorf A, Zondervan H. An epidemiological study of low-back pain in crane operators. *Ergonomics* 1990;33:981–7. doi:10.1080/00140139008925307

17 Burdorf A, Govaert G, Elders L. Postural load and back pain of workers in the manufacturing of prefabricated concrete elements. *Ergonomics* 1991;34:909–18. doi:10.1080/00140139108964834

18 Punnett L, Fine LJ, Keyserling WM, et al. Back disorders and nonneutral trunk postures of automobile assembly workers. *Scand J Work Environ Health* 1991;17:337–46. doi:10.5271/sjweh.1700

19 Bergqvist U, Wolgast E, Nilsson B, et al. Musculoskeletal disorders among visual display terminal workers: Individual, ergonomic, and work organizational factors. *Ergonomics* 1995;38:763–76. doi:10.1080/00140139508925148

20 Chiang HC, Ko YC, Chen SS, et al. Prevalence of shoulder and upper-limb disorders among workers in the fish-processing industry. *Scand J Work Environ Health* 1993;19:126–31. doi:10.5271/sjweh.1496

21 Silverstein BA, Fine LJ, Armstrong TJ. Occupational factors and carpal tunnel syndrome. *Am J Ind Med* 1987;11:343–58. doi:10.1002/ajim.4700110310

22 Van der Weele TJ, Knol MJ. A tutorial on interaction. *Epidemiol Methods* 2014;3:33–72. doi:10.1515/em-2013-0005

23 Rothman KJ, Greenland S, Walker AM. Concepts of interaction. *Am J Epidemiol* 1980;112:467–70. doi:10.1093/oxfordjournals.aje.a113015

24 Videman T, Nurminen T, Tola S, et al. Low-back pain in nurses and some loading factors of work. *Spine (Phila Pa 1976)* 1984;9:400–4. doi:10.1097/00007632-198405000-00013

25 Marras WS, Lavender SA, Leurgans SE, et al. Biomechanical risk factors for occupationally related low back disorders. *Ergonomics* 1995;38:377–410. doi:10.1080/00140139508925111

26 Riihimäki H, Tola S, Videman T, et al. Low-back pain and occupation. A cross-sectional questionnaire study of men in machine operating, dynamic physical work, and sedentary work. *Spine (Phila Pa 1976)* 1989;14:204–9.

27 Ministry of Government Legislation. Labor Standards Act. *Laws on Green Growth, and Economic Investment in Korea*. https://www.law.go.kr/LSW/eng/engLsSc.do?menuld=2&secTion=lawNm&query=Labor+Standards+Act&x=0&y=0#liBgcolor0 (Accessed 26 May 2020).

28 Jeong MJ. Analysis on the actual conditions of safety management about small sized enterprises—Focused on to small enterprises in Kyunggi area. *J Korea Saf Manag Sci* 2007;9;47–54.

29 Szeto GPY, Wong TKT, Law RKY, et al. The impact of a multifaceted ergonomic intervention program on promoting occupational health in community nurses. *Appl Ergon* 2013;44:414–22. doi:10.1016/j.apergo.2012.10.004

30 Aghilinejad M, Bahrami-Ahmadi A, Kabir-Mokamelkhah E, et al. The effect of three ergonomics training programs on the prevalence of low-back pain among workers of an Iranian automobile factory: a randomized clinical trial. *Int J Occup Environ Med* 2014;5:65–71.

31 Aghilinejad M, Kabir-Mokamelkhah E, Labbafinejad Y, et al. The role of ergonomic training interventions on decreasing neck and shoulders pain among workers of an Iranian automobile factory: A randomized trial study. *Med J Islam Repub Iran* 2015;29:190.

32 Hignett S. Intervention strategies to reduce musculoskeletal injuries associated with handling patients: A systematic review. *Occup Environ Med* 2003;60:E6. doi:10.1136/oem.60.9.e6

33 Baron SL, Hales TR, Hurrell J. Evaluation of symptom surveys for occupational musculoskeletal disorders. *Am J Ind Med* 1996;29:609–17. doi:10.1002/(SICI)1097-0274(199606)29:6<609::AID-AJIM5>3.0.CO;2-E

34 Hünting W, Läubli T, Grandjean E. Postural and visual loads at VDT workplaces. I. Constrained postures. *Ergonomics* 1981;24:917-31. doi:10.1080/00140138108924

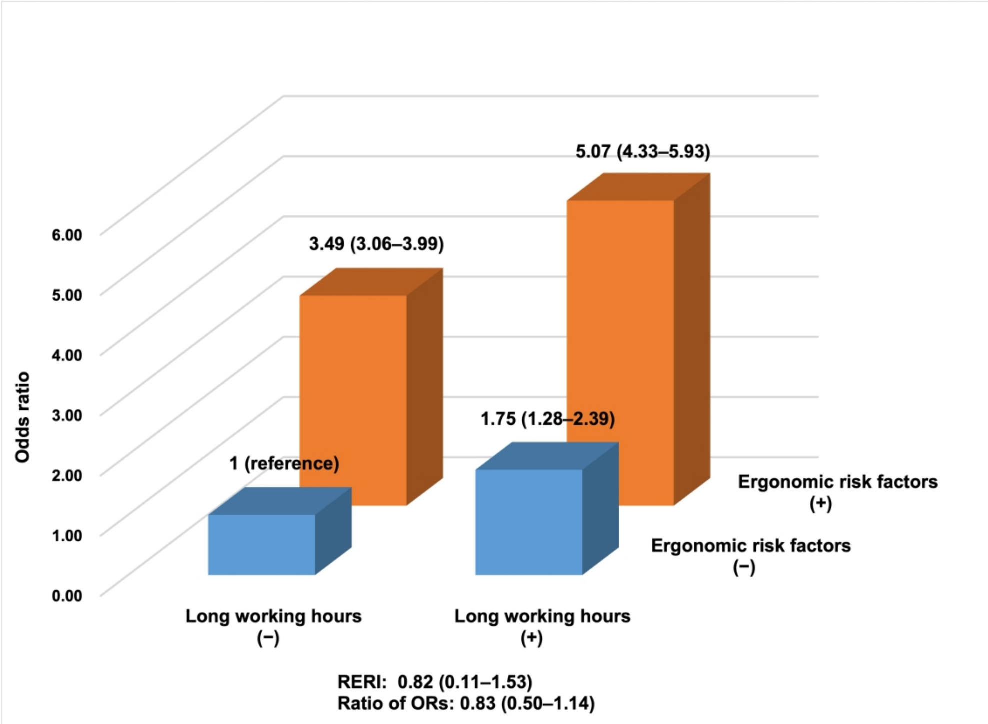
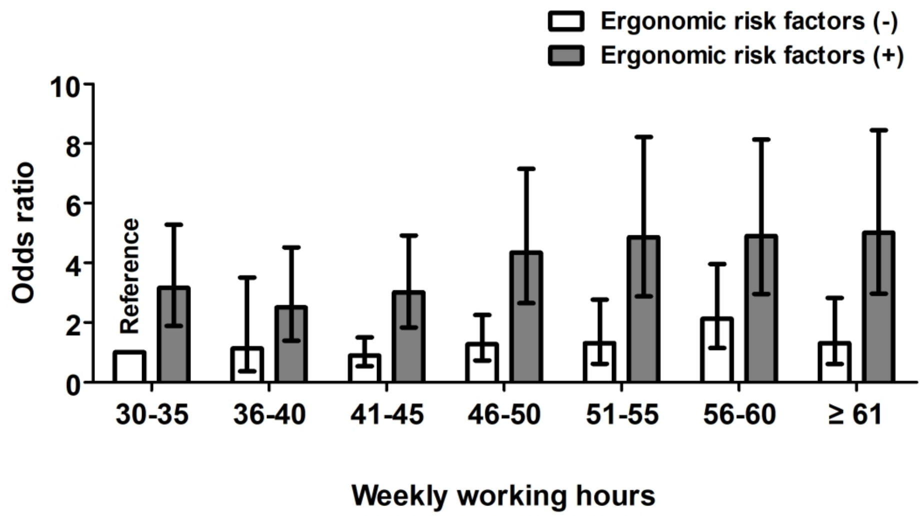


Figure 1. Combined effect of long working hours and ergonomic risk factors on musculoskeletal symptoms. Age, sex, education, income, employment, and shift work were adjusted in the model. RERI: relative excess risk due to interaction.

267x195mm (300 x 300 DPI)



Supplementary figure 1. Association weekly working hours and musculoskeletal symptoms by ergonomic risk factors. Survey weighted multiple logistic regression was used and age, sex, education, income, employment, and shift work were included in the model.

199x109mm (300 x 300 DPI)

Supplementary table 1. Interaction effect of long working hours and heavy load on backpain

	Long working hours (−)[a] OR(95% CI): *P*	Long working hours (+)[b] OR(95% CI): *P*	OR for long working hours (−)[a] vs. long working hours (+)[b] within strata of heavy load OR(95% CI): *P*
Heavy load (-)	Reference	1.73(1.45-2.07): <0.001	1.75(1.28–2.39): <0.001
Heavy load (+)	2.21(1.90-2.58): <0.001	3.93(3.10-4.97): <0.001	1.77(1.38–2.27): <0.000
OR for Heavy load (-) vs. (+) within strata of long working hours	2.21(1.90-2.58): <0.001	2.27(1.74-2.95): <0.001	
Measure of interaction on additive scale: RERI	0.98(0.06-1.90): 0.038		
Measure of interaction on multiplicative scale: ratio of ORs	1.02(0.76-1.39): 0.879		

[a]Long working hours (−): ≤30 and ≤52 hours; [b]Long working hours (+): >52 hours; OR: odds ratio; CI: confidence interval; RERI: relative excess risk due to interaction. Age, sex, education, income, employment, and shift work were adjusted for in the model.

Supplementary table 2. Interaction effect of long working hours and painful position on neck and upper limb pain

	Long working hours (−)[a] OR(95% CI): *P*	Long working hours (+)[b] OR(95% CI): *P*	OR for long working hours (−)[a] vs. long working hours (+)[b] within strata of painful position OR (95% CI): *P*
Painful position (-)	Reference	1.38(1.17-1.63): <0.001	1.38(1.17-1.63): <0.001
Painful position (+)	3.76(3.41-4.13): <0.001	5.44(4.69-6.30): <0.001	1.45(1.25-1.67): <0.000
OR for painful position (-) vs. painful position (+) within strata of long working hours	3.76(3.41-4.13): <0.001	3.93(3.23-4.77): <0.001	
Measure of interaction on additive scale: RERI	1.30(0.53-2.06): 0.001		
Measure of interaction on multiplicative scale: ratio of ORs	1.05(0.84-1.30): 0.688		

[a]Long working hours (−): ≤30 and ≤52 hours; [b]Long working hours (+): >52 hours; OR: odds ratio; CI: confidence interval; RERI: relative excess risk due to interaction. Age, sex, education, income, employment, and shift work were adjusted for in the model.

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4
Objectives	3	State specific objectives, including any prespecified hypotheses	4
Methods			
Study design	4	Present key elements of study design early in the paper	5
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	5
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	NA
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6,7,8
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	6,7,8
Bias	9	Describe any efforts to address potential sources of bias	6,7,8
Study size	10	Explain how the study size was arrived at	6,7,8
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	6,7,8
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	7,8
		(*b*) Describe any methods used to examine subgroups and interactions	7,8, 9
		(*c*) Explain how missing data were addressed	NA
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy	7,8
		(*e*) Describe any sensitivity analyses	NA

Continued on next page

Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	6
		(b) Give reasons for non-participation at each stage	6
		(c) Consider use of a flow diagram	NA
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	10-13
		(b) Indicate number of participants with missing data for each variable of interest	10-13
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	NA
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	NA
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	NA
		Cross-sectional study—Report numbers of outcome events or summary measures	10-18
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	10-18
		(*b*) Report category boundaries when continuous variables were categorized	10-18
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	10-19
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	NA
Discussion			
Key results	18	Summarise key results with reference to study objectives	19
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	21
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	19-21
Generalisability	21	Discuss the generalisability (external validity) of the study results	19
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	22

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

BMJ Open

Influence of co-exposure to long working hours and ergonomic risk factors on musculoskeletal symptoms: An interaction analysis

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2021-055186.R2
Article Type:	Original research
Date Submitted by the Author:	22-Apr-2022
Complete List of Authors:	Park, Jeongwoo; Dong-A University College of Medicine, Kang, Mo-Yeol ; Catholic University of Korea College of Medicine, Occupational and environment meidcine Kim, Jung Il; Dong-A University College of Medicine, Department of Occupational & Environmental Medicine Hwang, Jong-Hyun ; Dong-A University College of Medicine, Occupational and environmental medicine Choi, Seong-Soo; University of Ulsan College of Medicine, Cho, Seong-Sik; Dong-A University, Department of Occupational and Environmental Medicine
Primary Subject Heading:	Occupational and environmental medicine
Secondary Subject Heading:	Epidemiology
Keywords:	EPIDEMIOLOGY, OCCUPATIONAL & INDUSTRIAL MEDICINE, Musculoskeletal disorders < ORTHOPAEDIC & TRAUMA SURGERY

Influence of co-exposure to long working hours and ergonomic risk factors on musculoskeletal symptoms: An interaction analysis

Jeong-Woo Park, MD[1]; Mo-Yeol Kang, MD[2]; Jung-Il Kim, MD[1]; Jong-Hyun Hwang, MD[3]; Seong-Soo Choi[4], Seong-Sik Cho, MD[1]*

[1]Department of Occupational and Environmental Medicine, College of Medicine, Dong-A University, Busan, Korea

[2]Department of Occupational and Environmental Medicine, Seoul St. Mary's Hospital, College of Medicine, The Catholic University of Korea, Seoul, Korea

[3]Department of Occupational and Environmental Medicine, Dong-A University hospital, Busan, Korea

[4]Department of Anesthesiology and Pain Medicine, Asan Medical Center, University of Ulsan College of Medicine

***Corresponding Author**: Seong-Sik Cho

Department of Occupational and Environmental Medicine, College of Medicine

Dong-A University

32 Daesingongwon-ro, Seo-gu, Busan 49201, Korea

Phone: 82 10-4920-9725

Fax: 051-242-8428

Email: sscho@dau.ac.kr

Word Count (excluding title page, abstract, references, figures and tables): 2801words

Objectives

This study explores the interaction between ergonomic risk factors and long working hours on musculoskeletal symptoms by additive and multiplicative scales.

Design

We used the data of the fifth Korean working condition survey (KWCD). The KWCD is a cross-sectional study.

Setting

To represent the entire Korean working population, the probability proportion stratified cluster sampling method was used. The face-to-face interview was carried out with a structured questionnaire.

Main outcomes and measures

To assess the combined effect of ergonomic risk factors and long working hours on musculoskeletal symptoms, the relative excess risk due to interaction (RERI) and the ratio of odds ratios (ORs) were calculated using multiple survey-weighted logistic analysis and post-estimation commands

Results

The OR for musculoskeletal symptoms was 1.75 (95% confidence interval [CI] = 1.28–1.39) for exposure to long working hours, 3.49 (95% CI = 3.06–3.99) for exposure to ergonomic risk factors, and 5.07 (95% CI = 4.33–5.93) for co-exposure to long working hours and ergonomic risk factors. The RERI was 0.82 (95% CI = 0.11–1.53), and the ratio of ORs was 0.83 (95% CI = 0.50–1.14)

Conclusion

Our findings suggest that co-exposure to both ergonomic risk factors and long working hours

has a supra-additive interaction effect on musculoskeletal symptoms. Regulations on working hours and workplace interventions might reduce the musculoskeletal diseases of workers.

Strength & Limitation of this study

This study analyzed a nationally representative sample (the KWCS) with a large sample size (34,316).

This study conducted interaction analysis in both additive and multiplicative scales.

The causality between exposures and musculoskeletal disorders could not be established due to the nature of the study design (a cross-sectional study).

Self-reporting of working hours and musculoskeletal symptoms may lead to information bias.

The potential confounders, such as body mass index, previous history of musculoskeletal diseases, were not assessed in this study.

INTRODUCTION

Musculoskeletal disorders are an important work-related health issue worldwide, as they increase medical costs due to their high prevalence.[1] Work-related musculoskeletal disorders account for 40% of all work-related medical expenses worldwide.[2] In South Korea, they accounted for 57.6% of all work-related diseases in 2018.[3] A variety of risk factors, including physical and psychosocial factors, are associated with musculoskeletal disorders. Ergonomic risk factors, such as awkward or painful posture, heavy physical workload, lifting and forceful movements, and repetitive hand or arm movements, are well-known risk factors of musculoskeletal disorders.[4] Moreover, an increased risk of developing work-related musculoskeletal disorders is linked to psychosocial factors, including poor job control and low social support.[5, 6]

Long working hours can be harmful to workers' health and well-being, and are linked to physical health problems such as atrial fibrillation, coronary heart disease, stroke, occupational injury, depression, and suicidal ideation.[7–11] The Korean government has acknowledged the adverse effects of excessive working hours and has legally stipulated a maximum of 52 working hours per week. However, the average annual working hours of Korea were still 1,967 hours in 2019, which is 241 more hours than in OECD countries.[12]

Long working hours imply that workers in a hazardous working environment are exposed to risks for longer periods. Thus, co-exposure to long working hours combined with other occupational risk factors could be more harmful. From this perspective, co-exposure to long working hours and ergonomic risk factors may lead to a higher prevalence of musculoskeletal disorders in the workplace. However, few studies have reported the combined effect of long working hours and ergonomic risk factors on musculoskeletal

disorders, particularly using both additive and multiplicative scales. Thus, this study aimed to identify the combined effect of long working hours and ergonomic risk factors on musculoskeletal symptoms by interaction analysis on both additive and multiplicative scales.

METHODS

Study participants

We used a data sample from the fifth Korean Working Condition Survey (KWCS), conducted by the Korea Occupational Safety and Health Agency (KOSHA). The KWCS is comparable to the European Working Conditions Survey; it aims to survey the working conditions in various occupations. The sample from the fifth KWCS was recruited from 17 cities and provinces in Korea and excludes individuals younger than 15 years.

The target population included nationwide employed individuals aged 15 years or older in all Korean households in 2017. The survey was conducted through face-to-face interviews after obtaining consent from the participants. Students, stay-at-home spouses, unemployed, and retired individuals were excluded to ensure that the sample represented the economically active population. A sample design was constructed using a secondary probability proportion stratified cluster sample survey. Census districts were chosen based on the number of households. Thereafter, in each selected census district, ten households were randomly selected. Finally, one randomly selected eligible person in each household was interviewed (eligible persons were individuals employed at the point of the survey). The data of the fifth KWCS used design-weight to adjust the non-response rate and sample selection. In addition, the raking ratio method was used for post-stratification to adjust for the characteristics of gender, age, region, locality, and occupation.

Of the total 50,205 employees (unweighted sample size = 50,205), 34,316 wage workers (unweighted sample size = 27,927)—excluding self-employed, unpaid family workers, and employers—were included in the analysis. Only employees whose weekly working hours totaled more than 30 hours were included to exclude the impact of incomplete employment.

Patient and public involvement

Participants in the study were not involved in the design of the study. The raw data of KWCS is available to the public. The study findings were only published in peer-reviewed journals, with no other information about the results provided to participants.

Ethical considerations

The data used in our study are the fifth Korean working condition survey which is open to the public with personally identifiable information deleted. The need for written informed consent was waived off, and this study was approved by the Institutional Review Board of Dong-A University Hospital (Approval No: DAUHIRB-TEMP-20-212).

Study variables

All study variables were collected from the KWCS questionnaire. Sociodemographic variables included gender, age, educational level, and income. Age was divided into five categories: <30, 30–39, 40–49, 50–59, ≥60. Education was classified according to three levels: middle school or less, high school graduate, or college or more. Monthly income was categorized into quartiles. Employment status was classified into three categories: regular, temporary, and daily. Shift work was classified into two categories (yes or no). The information about working hours per week was collected using the following question: "How many hours do you work per week?" Answers were divided into two categories: 30–52 h/week was classed as "standard working hours," while more than 52 h/week was classed as "long working hours."

Exposure to ergonomic risk factors was assessed using a questionnaire. First, the percentage of time that workers were exposed to a specific motion or posture during their working time was recorded. There were five items assessing ergonomic risk factors, namely tiring or painful position, lifting or moving people, carrying or moving heavy loads, continuous standing, and repetitive hand or arm movements.[4] For each item, the results were dichotomized into "with exposure" when the exposure time was half of the working hours or more per day, or "without exposure" when the exposure time was less than half of the working hours per day. Finally, if any of the five items were reported as "with exposure," "ergonomic risk factor" was considered present, while if all five items were reported as "without exposure," "ergonomic risk factor" was considered not present.

Musculoskeletal symptoms were present when workers had any of the three following symptoms: neck and upper limb (shoulder, arm, elbow, wrist, hand) pain, lower limb (feet, knee, legs, hips) pain, or back pain during the last 12 months. Musculoskeletal symptoms were considered not present when workers had none of the three musculoskeletal problems (pain in neck and upper limb, lower limb, or back).

Statistical analysis

The characteristics of study participants (expressed in counts and proportions) were demonstrated according to long working hours by using chi-squared tests. To investigate the risk of musculoskeletal symptoms, a survey-weighted multiple logistic analysis was used. Other potential confounding variables—including age, sex, education level, income, shift work, and employment status—were adjusted in the model. Also, by the weekly working hours and exposure to ergonomic risk factors OR ratios for musculoskeletal symptoms were estimated. Finally, the relative excess risk due to interaction (RERI) and ratio of odds ratios (ORs) were estimated to perform the interaction analysis between long working hours and ergonomic risk factors. The ratio of ORs and 95% confidence interval (CI), which were calculated by the post-estimation commands “linear combination of coefficients” (lincom), estimated the combined effects based on multiplicative scales. The RERI and 95% CI, which were calculated by the post-estimation commands “nonlinear combination of coefficients” (nlcom), estimated the combined effects based on additive scale. Stata version 16.1 software was used for all statistical analyses, with a two-tailed statistical significance level of $p < 0.05$.

For an additive scale of the interaction between long working hours and ergonomic risk factor, RERI was estimated;

$$RERI = OR_{\text{combined exposure to long working hours and ergonomic factor}} - OR_{\text{exposure to only ergonomic factor}} - OR_{\text{exposure to only long working hours}} + 1$$

For a multiplicative scale of the interaction between long working hours and ergonomic risk factors, the ratio of ORs was estimated:

$$OR_{\text{combined exposure to long working hours and ergonomic factor}} / (OR_{\text{exposure to only ergonomic factor}} * OR_{\text{exposure to only long working hours}})$$

In the epidemiologic study, if the RERI was greater than 0, it indicates there is a supra-additive interaction of two concurrent exposures. If the estimated ratio of the ORs was greater than 1, it indicates there is a supra-multiplicate interaction of two simultaneous exposures.[13]

RESULTS

Of the 34,316 study participants (unweighted sample size = 27,927), 14,104 (41%) were female. We observed that 14.4% of Korean employees worked more than 52 hours per week (Table 1). Higher proportions of participants reporting long working hours were found among males (17%), older adults (24%), high school graduates (23%), and low–middle income (18%) workers. Regarding work-related variables, workers with temporary jobs (20%) and shift work (23%) had the highest percentage of long working hours. In addition, workers who were exposed to ergonomic risk factors were more likely to report long working hours.

Table 1. Characteristics of study population

	Total		Long working hours (−)[a]		Long working hours (+)[b]		
	n	Proportion	*n*	Proportion	*n*	Proportion	*p*-value *
Gender	34316						<0.001
Male	20212	0.59	16730	0.83	3482	0.17	
Female	14104	0.41	12636	0.90	1468	0.10	

Age							<0.001
15–29	6233	0.18	5319	0.85	913	0.15	
30–39	8874	0.26	7846	0.88	1028	0.12	
40–49	9025	0.26	7870	0.87	1154	0.13	
50–59	7084	0.21	5963	0.84	1120	0.16	
≥60	3101	0.09	2367	0.76	734	0.24	
Education							<0.001
Middle school or less	2265	0.06	1178	0.79	487	0.21	
High school	10534	0.31	8115	0.77	8119	0.23	
College or more	21493	0.63	19450	0.90	2043	0.10	
Employment							<0.001
Regular	29375	0.86	25362	0.86	4012	0.14	
Temporary	3524	0.10	2822	0.80	701	0.20	
Daily	1418	0.04	1182	0.83	237	0.17	
Income							<0.001
Lowest	5060	0.16	4449	0.88	611	0.12	
Low–middle	7970	0.25	6555	0.82	1415	0.18	
High–middle	9365	0.29	7838	0.84	1528	0.16	

Highest	9826	0.30	8688	0.88	1138	0.12	
Shift work							<0.001
No	30236	0.88	26221	0.87	4014	0.13	
Yes	4073	0.12	3144	0.77	928	0.23	
Ergonomic risk factors							<0.001
Risk factors (−)	8775	0.26	8069	0.92	707	0.08	
Risk factors (+)	25533	0.74	21292	0.83	4241	0.17	

[a]Long working hours (−): ≤ 30 and ≤52 hours

[b]Long working hours (+): > 52 hours

*Estimated by survey-weighted χ^2 test

Table 2 shows the relationship between independent variables and musculoskeletal symptoms. Ergonomic risk factors (OR = 3.37; 95% CI = 2.99–3.80), long working hours (OR = 1.51, 95% CI = 1.36–1.67), female workers (OR = 1.21, 95% CI = 1.11–1.32), and shift workers (OR = 1.29, 95% CI = 1.15–1.44) were more likely to report musculoskeletal symptoms. Compared with regular workers, temporary workers were less likely (OR = 0.82, 95% CI = 0.73–0.93) and daily workers were more likely to experience musculoskeletal symptoms (OR = 2.13, 95% CI = 1.81–2.49). Regarding education level, workers with middle school graduation or less (OR = 3.10, 95% CI = 2.65–3.63) and those with high school graduation (OR = 1.86, 95% CI = 1.69–2.04) had a higher risk of musculoskeletal symptoms than college graduates or more. However, there was no statistically significant association between income and musculoskeletal symptoms.

Table 2. Factors associated with musculoskeletal symptoms by survey-weighted multiple logistic analysis (population size=32,184)

	Odds ratio	95% Confidence interval		*p*-value
Weekly working hours				
30–52	Reference			
>52	1.51	1.36	1.67	<0.001
Ergonomic risk factor				
Risk factor (-)	Reference			
Risk factor (+)	3.37	2.99	3.80	<0.001
Employment				
Regular	Reference			
Temporary	0.82	0.73	0.93	<0.001
Daily	2.13	1.81	2.49	<0.001
Shift work				
No	Reference			
Yes	1.29	1.15	1.44	<0.001
Income				
Highest	Reference			
High–middle	1.02	0.89	1.18	0.735
Low–middle	1.04	0.92	1.18	0.533

Lowest	1.07	0.96	1.19	0.244
Education				
College or more	Reference			
High school	1.86	1.69	2.04	<0.001
Middle school or less	3.10	2.65	3.63	<0.001
Gender				
Male	Reference			
Female	1.21	1.11	1.32	< 0.001
Age				
15–29	Reference			
30–39	1.88	1.60	2.21	<0.001
40–49	2.31	1.98	2.69	<0.001
40–59	2.55	2.19	2.98	<0.001
≥60	2.18	1.82	2.61	<0.001

ORs: odds ratios; CI: confidence interval

musculoskeletal symptoms.

The effects of weekly work hours and ergonomic risk factors on musculoskeletal symptoms are shown in Table 3 and supplementary figure 1. Ergonomic risk factors increased the risk of musculoskeletal symptoms in same working hours groups. The OR (0.90, 95%CI: 0.54-1.50) was lowest for workers who were not exposed to ergonomic risk factors with their 41-45 working hours and the OR (2.51, 95%CI: 1.39-4.52) was lowest for workers with standard work hours (36-40) who were exposed to ergonomic risk factors.

Additionally, when working hours exceeded the standard working hours, the risk of musculoskeletal symptoms gradually increased among workers exposed to ergonomic risk factors. The odds ratio (OR) was highest (5.01, 95 percent CI: 2.97-8.45) among employees with ergonomic risk factors and more than 60 weekly work hours.

Table 3. Association weekly working hours and musculoskeletal symptoms by ergonomic risk factors

	Ergonomic risk factors (-)				Ergonomic risk factors (+)			
	Odds ratio	95% CI		p	Odds ratio	95% CI		p
Weekly working hours								
30-35 hours	Reference				3.16	1.89	5.28	<0.001
36-40 hours	1.14	0.37	3.51	0.826	2.51	1.39	4.52	0.002
41-45 hours	0.90	0.54	1.50	0.677	3.01	1.84	4.92	<0.001
46-50 hours	1.28	0.73	2.25	0.385	4.35	2.65	7.15	<0.001
51-55 hours	1.31	0.62	2.77	0.482	4.86	2.88	8.22	<0.001
56-60 hours	2.13	1.15	3.96	0.017	4.90	2.95	8.14	<0.001
61- hours	1.31	0.61	2.83	0.490	5.01	2.97	8.45	<0.001

Survey weighted multiple logistic regression was employed, and age, sex, education, income, employment, and shift work were adjusted in the model.

Table 4 and figure 1 show the effect of the interaction between long working hours and ergonomic risk factors on musculoskeletal symptoms. For long working hours without ergonomic risk factors, the OR for musculoskeletal symptoms was 1.75 (95 % CI = 1.28–1.39). For ergonomic risk factors without long working hours, the OR of musculoskeletal symptoms was 3.49 (95% CI = 3.06–3.99). In addition, if workers were exposed to simultaneous long working hours and ergonomic risk factors, the OR for musculoskeletal symptoms was 5.07 (95% CI = 4.33–5.93). The RERI was 0.82 (95% CI = 0.11–1.53), and the ratio of ORs was 0.83 (95% CI = 0.50–1.14). Thus, we observed a supra-additive interaction between long working hours and ergonomic risk factors regarding their effect on musculoskeletal symptoms

Supplementary tables demonstrate the interaction between long working hours and heavy load on back pain and between long working hours and painful position on neck and upper limb pains. RERI for long working hours and heavy load on back pain was 0.98 (95%CI: 0.06-1.90), and RERI for long working hours and painful position on neck and upper limb pains was 1.30 (95%CI: 0.53-2.06). This study observed supra-additive interactions between long working hours and heavy load on back pain and between long working hours and painful position on neck and upper limb pains.

Table 4. Interaction effect of long working hours and ergonomic risk factors on musculoskeletal symptoms

	Long working hours (−)[a] OR (95% CI): *P*	Long working hours (+)[b] OR (95% CI): *P*	OR for long working hours (−)[a] vs. long working hours (+)[b] within strata of ergonomic risk factor OR (95% CI): *P*
Ergonomic risk factors (-)	Reference	1.75 (1.28–2.39): <0.001	1.75 (1.28–2.39): <0.001
Ergonomic risk factors (+)	3.49 (3.06–3.99): <0.001	5.07 (4.33–5.93): <0.001	1.45 (1.30–1.61): <0.000
OR for ergonomic risk factors (-) vs. ergonomic risk factors (+) within strata of long working hours	3.49 (3.06–3.99): <0.001	2.89 (2.14–3.90): <0.001	
Measure of interaction on additive scale: RERI	0.82 (0.11–1.53): 0.024		
Measure of interaction on multiplicative scale: ratio of ORs	0.83 (0.50–1.14): 0.256		

[a]Long working hours (−): ≤30 and ≤52 hours; [b]Long working hours (+): >52 hours; OR: odds ratio; CI: confidence interval; RERI: relative excess risk due to interaction. Age, sex, education, income, employment, and shift work were adjusted for in the model.

DISCUSSION

The current study results showed that long working hours and ergonomic risk factors are associated with musculoskeletal symptoms. These results share similarities with previous studies showing that long working hours increased the risk of back pain and the diagnosis of neck and shoulder disorders, and that ergonomic risk factors such as heavy physical work, lifting movements, and awkward postures can increase the risk of lower back pain.[4, 14–18] Furthermore, repetitive work was also found to be associated with musculoskeletal disorders of the neck, shoulder, hand, and wrist.[4, 19–21]

When working hours were divided into smaller scales, workers exposed to ergonomic risk factors had the lowest OR for musculoskeletal symptoms when working standard work hours." Given the study's design (a cross-sectional study) and considering healthy worker effect, workers with musculoskeletal symptoms may reduce their working hours.

There was a synergy between long working hours and ergonomic risk factors on musculoskeletal symptoms. To the best of our knowledge, few studies have analyzed the combined effect of ergonomic risk factors and long working hours via interaction analysis on both additive and multiplicative scales. The most appropriate method is to report interactions by using both scales.[22, 23] Therefore, in this study, RERI (an additive scale) and ratio of ORs (a multiplicative scale) were calculated to conduct an interaction analysis. Although no statistical significance was observed on the multiplicative scale, RERI was greater than 0, which indicates the supra-additive interaction between long working hours and ergonomic risk factors. We observed a synergistic effect of the co-exposure to long work hours and ergonomic risk factors on musculoskeletal symptoms that was more detrimental than a simple addition of harmful effects by each exposure. As seen in supplementary tables, similar supra-additive interactions were observed in long working hours and heavy load on back pain, and long working hours and painful position on the neck and upper limbs. This finding is consistent with the results of table 4. This result may support the main hypothesis of the study.

As long working hours imply prolonged exposure to ergonomic risk factors (e.g., repetitive tasks, heavy lifting, and uncomfortable posture) and insufficient recovery, the interaction of long working hours and ergonomic risk factors can lead to a higher risk of musculoskeletal symptoms, compared with their simple additive effect. Several studies have suggested a dose-response relationship between co-existing ergonomic risk factors, such as workload, lifting, and awkward posture.[24–26] However, the results of this study suggest that the supra-additive interaction between long working hours and ergonomic risk factors can worsen the problem.

The current study proposed that stricter regulation of working hours is required. In 2018, concerns over the long working hours of Korean workers led the government to limit the legal working hours to 52 hours or fewer per week. However, regulations on working hours are not strict and are applied only to large enterprises with 300 or more employees.[27] This means that employees in small-scale workplaces have a higher risk of working long hours.[28] In addition, it is well known that employees in small-scale workplaces work under unfavorable conditions more often than those in large-scale workplaces. Implementing legal systems prohibiting long working hours, especially more than 52 hours, may help reduce the prevalence of musculoskeletal symptoms, particularly among workers in small-scale workplaces. Moreover, working conditions should be improved. As such, multifocal ergonomic interventions programs, such as training in ergonomic principles, workstation modification (modifying working postures), surveying ergonomics, and exercise programs, are recommended to reduce musculoskeletal symptoms and the risk of developing musculoskeletal disorders.[29–32]

This study had several limitations. First, it was a cross-sectional study; therefore, causality between exposure and musculoskeletal disorders could not be established because of the nature of the study design. However, when employees have musculoskeletal pain, they could not extend their working hours, owing to their symptoms. Therefore, the possibility of a reverse causal relationship between long working hours and musculoskeletal symptoms is low. Second, the assessment of working hours and musculoskeletal symptoms was self-reported, which can lead to information bias. Third, this study did not consider other possible confounders, such as past medical history of injury, exercise, and body mass index, which could affect musculoskeletal symptoms. Fourth, we assessed musculoskeletal symptoms instead of musculoskeletal disorders. However, musculoskeletal symptoms are highly correlated with physical findings of musculoskeletal disorders as well as accompanying or preceding musculoskeletal diseases.[33, 34] Therefore, to prevent the occurrence of work-related musculoskeletal disorders, it makes sense to investigate the musculoskeletal symptoms in the workplace.

In conclusion, the findings of this study suggest that long working hours combined with ergonomic risk factors can have harmful synergistic effects on musculoskeletal symptoms. The health of workers who experience unfavorable working conditions, especially those concurrently exposed to ergonomic risk factors and long working hours, could be improved by reduced working hours and ergonomic improvement. Strict regulation of working hours and ergonomic intervention programs could be helpful to prevent musculoskeletal disease in the workplace.

Acknowledgments

This research is supported by the Dong-a University Research Fund. Funding is used for the publication charge and English proofreading. This research is an important part of a thesis for a Master's degree of Jeong Woo Park from the Graduate School of Dong-A University. The authors sincerely appreciate the support of the Occupational Safety and Health Research Institute (OSHRI) and the KOSHA for providing us with the raw data from the fifth KWCS.

Data Availability

Data are available upon reasonable request.

Authors' Contributions

Jeong-Woo Park: Writing—original draft, Writing—review & editing; **Mo-Yeol Kang**: Writing—review& editing: **Jung-Il Kim**: Writing—review & editing; **Jong-Hyun Hwang**: Writing—review & editing; **Seong-Soo Choi:** Writing—review & editing; **Seong-Sik Cho:** Conceptualization, formal analysis, methodology, writing—original draft, writing—review & editing. All authors have read and agreed to the published version of the manuscript.

Competing Interests Statement

The authors declare no conflicts of interest.

Ethics Approval Statement: The written informed consent and the review of the study was waived by the Institutional Review Board of Dong-A University Hospital (Approval No: DAUHIRB-TEMP-20-212).

Figure 1. Combined effect of long working hours and ergonomic risk factors on musculoskeletal symptoms. Age, sex, education, income, employment, and shift work adjusted in the model. RERI : relative excess risk due to interaction.

REFERENCES

1 Punnett L, Wegman DH. Work-related musculoskeletal disorders: the epidemiologic evidence and the debate. *J Electromyogr Kinesiol* 2004;14:13–23. doi: 10.1016/j.jelekin.2003.09.015.

2 Morken T, Riise T, Moen B, et al. Low back pain and widespread pain predict sickness absence among industrial workers. *BMC Musculoskelet Disord* 2003;4:21. doi: 10.1186/1471-2474-4-21.

3 Ministry of Employment and Labor. Yearbooks of industrial accident. http://kosha.or.kr/kosha/data/industrialAccidentStatus.do?mode=view&articleNo=410303&article.offset=0&articleLimit=10 (Accessed 10 Nov 2020).

4 Putz-Anderson V, Bernard B, Burt S, et al. Musculoskeletal disorders and workplace factors: A critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck, upper extremity, and low back. Cincinnati: NIOSH Publ., 97–141 1997.

5 Bergsten EL, Mathiassen SE, Vingård E. Psychosocial Work Factors and Musculoskeletal Pain: A Cross-Sectional Study among Swedish Flight Baggage Handlers. Biomed Res Int. 2015;2015:798042. doi:10.1155/2015/798042

6 Amin NA, Nordin R, Fatt QK, et al. Relationship between psychosocial risk factors and work-related musculoskeletal disorders among public hospital nurses in Malaysia. *Ann*

Occup Environ Med 2014;26:23. doi:10.1186/s40557-014-0023-2

7 Virtanen M, Heikkilä K, Jokela M, et al. Long working hours and coronary heart disease: A systematic review and meta-analysis. *Am J Epidemiol* 2012;176:586–96. doi:10.1093/aje/kws139

8 Kivimäki M, Jokela M, Nyberg ST, et al. Long working hours and risk of coronary heart disease and stroke: a systematic review and meta-analysis of published and unpublished data for 603,838 individuals. *Lancet* 2015;386:1739–46. doi:10.1016/S0140-6736(15)60295-1

9 Dembe AE, Erickson JB, Delbos RG, et al. The impact of overtime and long work hours on occupational injuries and illnesses: new evidence from the United States. *Occup Environ Med* 2005;62:588–97. doi:10.1136/oem.2004.016667

10 Amagasa T, Nakayama T. Relationship between long working hours and depression: A 3-year longitudinal study of clerical workers. *J Occup Environ Med* 2013;55:863–72. doi:10.1097/JOM.0b013e31829b27fa

11 Virtanen M, Ferrie JE, Singh-Manoux A, et al. Long working hours and symptoms of anxiety and depression: A 5-year follow-up of the Whitehall II study. *Psychol Med* 2011;41:2485–94. doi:10.1017/S0033291711000171

12 OECD statistics. Organization for economic co-operation and development. Average usual weekly hours worked on the main job. https://stats.oecd.org/Index.aspx?DataSetCode=AVE_HRS (Accessed 3 Nov 2017).

13 Knol MJ, VanderWeele TJ. Recommendations for presenting analyses of effect modification and interaction. Int J Epidemiol. 2012;41(2):514-520. doi:10.1093/ije/dyr218

14 Trinkoff AM, Le R, Geiger-Brown J, et al. Longitudinal relationship of work hours, mandatory overtime, and on-call to musculoskeletal problems in nurses. *Am J Ind Med* 2006;49:964–71. doi:10.1002/ajim.20330

15 Johansson JA, Rubenowitz S. Risk indicators in the psychosocial and physical work environment for work-related neck, shoulder and low back symptoms: a study among blue- and white-collar workers in eight companies. *Scand J Rehabil Med* 1994;26:131–42.

16 Burdorf A, Zondervan H. An epidemiological study of low-back pain in crane operators. *Ergonomics* 1990;33:981–7. doi:10.1080/00140139008925307

17 Burdorf A, Govaert G, Elders L. Postural load and back pain of workers in the manufacturing of prefabricated concrete elements. *Ergonomics* 1991;34:909–18. doi:10.1080/00140139108964834

18 Punnett L, Fine LJ, Keyserling WM, et al. Back disorders and nonneutral trunk postures of automobile assembly workers. *Scand J Work Environ Health* 1991;17:337–46. doi:10.5271/sjweh.1700

19 Bergqvist U, Wolgast E, Nilsson B, et al. Musculoskeletal disorders among visual display terminal workers: Individual, ergonomic, and work organizational factors. *Ergonomics* 1995;38:763–76. doi:10.1080/00140139508925148

20 Chiang HC, Ko YC, Chen SS, et al. Prevalence of shoulder and upper-limb disorders among workers in the fish-processing industry. *Scand J Work Environ Health* 1993;19:126–31. doi:10.5271/sjweh.1496

21 Silverstein BA, Fine LJ, Armstrong TJ. Occupational factors and carpal tunnel syndrome. *Am J Ind Med* 1987;11:343–58. doi:10.1002/ajim.4700110310

22 Van der Weele TJ, Knol MJ. A tutorial on interaction. *Epidemiol Methods* 2014;3:33–72. doi:10.1515/em-2013-0005

23 Rothman KJ, Greenland S, Walker AM. Concepts of interaction. *Am J Epidemiol* 1980;112:467–70. doi:10.1093/oxfordjournals.aje.a113015

24 Videman T, Nurminen T, Tola S, et al. Low-back pain in nurses and some loading factors of work. *Spine (Phila Pa 1976)* 1984;9:400–4. doi:10.1097/00007632-198405000-00013

25 Marras WS, Lavender SA, Leurgans SE, et al. Biomechanical risk factors for occupationally related low back disorders. *Ergonomics* 1995;38:377–410. doi:10.1080/00140139508925111

26 Riihimäki H, Tola S, Videman T, et al. Low-back pain and occupation. A cross-sectional questionnaire study of men in machine operating, dynamic physical work, and sedentary work. *Spine (Phila Pa 1976)* 1989;14:204–9.

27 Ministry of Government Legislation. Labor Standards Act. *Laws on Green Growth, and Economic Investment in Korea*. https://www.law.go.kr/LSW/eng/engLsSc.do?menuId=2&secTion=lawNm&query=Labor+Standards+Act&x=0&y=0#liBgcolor0 (Accessed 26 May 2020).

28 Jeong MJ. Analysis on the actual conditions of safety management about small sized enterprises—Focused on to small enterprises in Kyunggi area. *J Korea Saf Manag Sci* 2007;9;47–54.

29 Szeto GPY, Wong TKT, Law RKY, et al. The impact of a multifaceted ergonomic intervention program on promoting occupational health in community nurses. *Appl Ergon* 2013;44:414–22. doi:10.1016/j.apergo.2012.10.004

30 Aghilinejad M, Bahrami-Ahmadi A, Kabir-Mokamelkhah E, et al. The effect of three ergonomics training programs on the prevalence of low-back pain among workers of an Iranian automobile factory: a randomized clinical trial. *Int J Occup Environ Med* 2014;5:65–71.

31 Aghilinejad M, Kabir-Mokamelkhah E, Labbafinejad Y, et al. The role of ergonomic training interventions on decreasing neck and shoulders pain among workers of an Iranian automobile factory: A randomized trial study. *Med J Islam Repub Iran* 2015;29:190.

32 Hignett S. Intervention strategies to reduce musculoskeletal injuries associated with handling patients: A systematic review. *Occup Environ Med* 2003;60:E6. doi:10.1136/oem.60.9.e6

33 Baron SL, Hales TR, Hurrell J. Evaluation of symptom surveys for occupational musculoskeletal disorders. *Am J Ind Med* 1996;29:609–17. doi:10.1002/(SICI)1097-0274(199606)29:6<609::AID-AJIM5>3.0.CO;2-E

34 Hünting W, Läubli T, Grandjean E. Postural and visual loads at VDT workplaces. I. Constrained postures. *Ergonomics* 1981;24:917-31. doi:10.1080/001401381089249

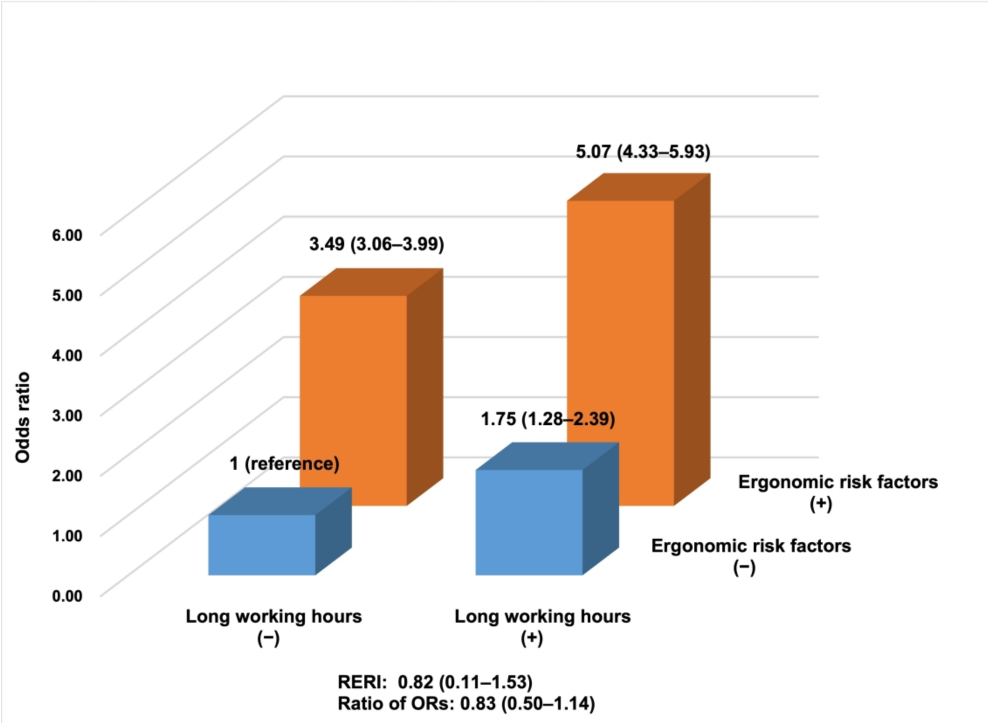
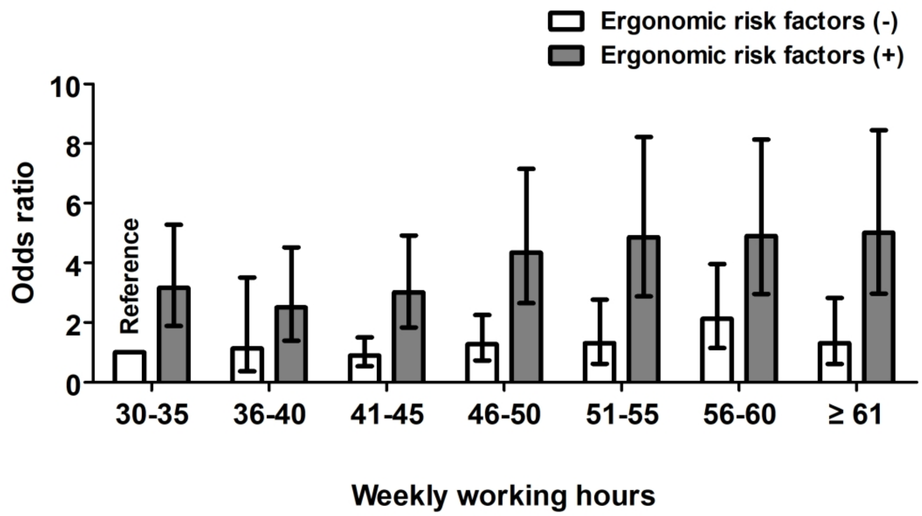


Figure 1. Combined effect of long working hours and ergonomic risk factors on musculoskeletal symptoms. Age, sex, education, income, employment, and shift work were adjusted in the model. RERI: relative excess risk due to interaction.



Supplementary figure 1. Association weekly working hours and musculoskeletal symptoms by ergonomic risk factors. Survey weighted multiple logistic regression was used and age, sex, education, income, employment, and shift work were included in the model.

199x109mm (300 x 300 DPI)

Supplementary table 1. Interaction effect of long working hours and heavy load on backpain

	Long working hours (−)[a] OR(95% CI): *P*	Long working hours (+)[b] OR(95% CI): *P*	OR for long working hours (−)[a] vs. long working hours (+)[b] within strata of heavy load OR(95% CI): *P*
Heavy load (-)	Reference	1.73(1.45-2.07): <0.001	1.75(1.28–2.39): <0.001
Heavy load (+)	2.21(1.90-2.58): <0.001	3.93(3.10-4.97): <0.001	1.77(1.38–2.27): <0.000
OR for Heavy load (-) vs. (+) within strata of long working hours	2.21(1.90-2.58): <0.001	2.27(1.74-2.95): <0.001	
Measure of interaction on additive scale: RERI	0.98(0.06-1.90): 0.038		
Measure of interaction on multiplicative scale: ratio of ORs	1.02(0.76-1.39): 0.879		

[a]Long working hours (−): ≤30 and ≤52 hours; [b]Long working hours (+): >52 hours; OR: odds ratio; CI: confidence interval; RERI: relative excess risk due to interaction. Age, sex, education, income, employment, and shift work were adjusted for in the model.

Supplementary table 2. Interaction effect of long working hours and painful position on neck and upper limb pain

	Long working hours (−)[a] OR(95% CI): *P*	Long working hours (+)[b] OR(95% CI): *P*	OR for long working hours (−)[a] vs. long working hours (+)[b] within strata of painful position OR (95% CI): *P*
Painful position (-)	Reference	1.38(1.17-1.63): <0.001	1.38(1.17-1.63): <0.001
Painful position (+)	3.76(3.41-4.13): <0.001	5.44(4.69-6.30): <0.001	1.45(1.25-1.67): <0.000
OR for painful position (-) vs. painful position (+) within strata of long working hours	3.76(3.41-4.13): <0.001	3.93(3.23-4.77): <0.001	
Measure of interaction on additive scale: RERI	1.30(0.53-2.06): 0.001		
Measure of interaction on multiplicative scale: ratio of ORs	1.05(0.84-1.30): 0.688		

[a]Long working hours (−): ≤30 and ≤52 hours; [b]Long working hours (+): >52 hours; OR: odds ratio; CI: confidence interval; RERI: relative excess risk due to interaction. Age, sex, education, income, employment, and shift work were adjusted for in the model.

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4
Objectives	3	State specific objectives, including any prespecified hypotheses	4
Methods			
Study design	4	Present key elements of study design early in the paper	5
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	5
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	NA
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6,7,8
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	6,7,8
Bias	9	Describe any efforts to address potential sources of bias	6,7,8
Study size	10	Explain how the study size was arrived at	6,7,8
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	6,7,8
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	7,8
		(*b*) Describe any methods used to examine subgroups and interactions	7,8, 9
		(*c*) Explain how missing data were addressed	NA
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy	7,8
		(*e*) Describe any sensitivity analyses	NA

Continued on next page

Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	6
		(b) Give reasons for non-participation at each stage	6
		(c) Consider use of a flow diagram	NA
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	10-13
		(b) Indicate number of participants with missing data for each variable of interest	10-13
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	NA
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	NA
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	NA
		Cross-sectional study—Report numbers of outcome events or summary measures	10-18
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	10-18
		(*b*) Report category boundaries when continuous variables were categorized	10-18
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	10-19
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	NA
Discussion			
Key results	18	Summarise key results with reference to study objectives	19
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	21
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	19-21
Generalisability	21	Discuss the generalisability (external validity) of the study results	19
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	22

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.