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

Journal:	<i>BMJ Open</i>
Manuscript ID	bmjopen-2021-055186
Article Type:	Original research
Date Submitted by the Author:	05-Jul-2021
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Keywords:	EPIDEMIOLOGY, OCCUPATIONAL & INDUSTRIAL MEDICINE, Musculoskeletal disorders < ORTHOPAEDIC & TRAUMA SURGERY

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4 **Influence of co-exposure to long working hours and ergonomic risk factors on**
5 **musculoskeletal symptoms: An interaction analysis**
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50
51
52 Word Count (excluding title page, abstract, references, figures and tables): 2310 words
53
54
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56
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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

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4 disorders, particularly using both additive and multiplicative scales. Thus, this study aimed to
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6 identify the combined effect of long working hours and ergonomic risk factors on
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8 musculoskeletal symptoms by interaction analysis, on both additive and multiplicative scales.
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11 12 13 **METHODS**

14 15 **Study participants**

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17 We used a data sample from the fifth Korean Working Condition Survey (KWCS),
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19 conducted by the Korea Occupational Safety and Health Agency (KOSHA). The KWCS is
20
21 comparable to the European Working Conditions Survey; it aims to survey the working
22
23 conditions in various occupations. The sample from the fifth KWCS was recruited from 17
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25 cities and provinces in Korea and excludes individuals younger than 15 years.
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29 The target population included nationwide employed individuals aged 15 years or
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31 older in all Korean households in 2017. The survey was conducted through face-to-face
32
33 interviews after obtaining consent from the participants. Students, stay-at-home spouses,
34
35 unemployed, and retired individuals were excluded to ensure that the sample represented the
36
37 economically active population. A sample design was constructed using a secondary
38
39 probability proportion stratified cluster sample survey. Census districts were chosen based on
40
41 the number of households. Thereafter, in each selected census district, 10 households were
42
43 randomly selected. Finally, interviews were conducted with one eligible person in each
44
45 household. The data of the fifth KWCS used design-weight to adjust the non-response rate
46
47 and sample selection. In addition, the raking ratio method was used for post-stratification to
48
49 adjust for the characteristics of gender, age, region, locality, and occupation.
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55 Of the total 50,205 employees (unweighted sample size = 50,205), 34,316 wage
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4 workers (unweighted sample size = 27,927)—excluding self-employed, unpaid family
5
6 workers, and employers—were included in the analysis. Only employees whose weekly
7
8 working hours totaled more than 30 hours were included to exclude the impact of incomplete
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10 employment.
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13 **Ethical considerations**

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16 The data used in our study are fifth Korean working condition survey which is open to the
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18 public with personally identifiable information deleted. The need for written informed
19
20 consent was waived off and this study was approved by the Institutional Review Board of
21
22 Dong-A University Hospital (Approval No: DAUHIRB-TEMP-20-212).
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25 **Study variables**

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27 All study variables were collected from the KWCS questionnaire. Sociodemographic
28
29 variables included gender, age, educational level, and income. Age was divided into five
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31 categories: <30, 30–39, 40–49, 50–59, ≥60. Education was classified according to three
32
33 levels: middle school or less, high school graduate, or college or more. Monthly income was
34
35 categorized into quartiles. Employment status was classified into three categories: regular,
36
37 temporary, and daily. Shift work was classified into two categories (yes or no). The
38
39 information about working hours per week was collected using the following question: “How
40
41 many hours do you work per week?” Answers were divided into two categories: 30–52
42
43 h/week was classed as “standard working hours,” while more than 52 h/week was classed as
44
45 “long working hours.”
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51 Exposure to ergonomic risk factors was assessed using a questionnaire. First, the
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53 percentage of time that workers were exposed to a specific motion or posture during their
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55 working time was recorded. There were five items assessing ergonomic risk factors, namely
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4 tiring or painful position, lifting or moving people, carrying or moving heavy loads,
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6 continuous standing, and repetitive hand or arm movements.[4] For each item, the results
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8 were dichotomized into “with exposure” when the exposure time was half of the working
9
10 hours or more per day, or “without exposure” when the exposure time was less than half of
11
12 the working hours per day. Finally, if any of the five items were reported as “with exposure,”
13
14 “ergonomic risk factor” was considered present, while if all five items were reported as
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16 “without exposure,” “ergonomic risk factor” was considered not present.
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21 Musculoskeletal symptoms were present when workers had any of the three
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23 following symptoms: neck and upper limb (shoulder, arm, elbow, wrist, hand) pain, lower
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25 limb (feet, knee, legs, hips) pain, or back pain during the last 12 months. Musculoskeletal
26
27 symptoms were considered not present when workers had none of the three musculoskeletal
28
29 problems (pain in neck and upper limb, lower limb, or back).
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31

32 **Statistical analysis**

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34 The characteristics of study participants (expressed in counts and proportions) were
35
36 examined according to long working hours using chi-squared tests. To investigate the risk of
37
38 musculoskeletal symptoms, a survey-weighted multiple logistic analysis was used. Other
39
40 potential confounding variables—including age, sex, education level, income, shift work, and
41
42 employment status—were adjusted in the model. Next, the relative excess risk due to
43
44 interaction (RERI) and ratio of odds ratios (ORs) were estimated to perform the interaction
45
46 analysis between long working hours and ergonomic risk factors. The ratio of ORs and 95%
47
48 confidence interval (CI), which were calculated by the post-estimation commands “linear
49
50 combination of coefficients” (lincom), estimated the combined effects based on
51
52 multiplicative scales. The RERI and 95% CI, which were calculated by the post-estimation
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4 commands “nonlinear combination of coefficients” (nlcom), estimated the combined effects
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6 based on additive scale. Stata version 16.1 software was used for all statistical analyses, with
7
8 a two-tailed statistical significance level of $p < 0.05$.
9

10
11 For an additive scale of the interaction between long working hours and ergonomic
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13 risk factor, RERI was estimated;
14

$$15 \quad \text{RERI} = \text{OR}_{\text{combined exposure to long working hours and ergonomic factor}} - \text{OR}_{\text{exposure to only ergonomic factor}} -$$
$$16 \quad \text{OR}_{\text{exposure to only long working hours}} + 1$$

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20 For a multiplicative scale of the interaction between long working hours and
21
22 ergonomic risk factors, the ratio of ORs was estimated:
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$$24 \quad \text{OR}_{\text{combined exposure to long working hours and ergonomic factor}} / (\text{OR}_{\text{exposure to only ergonomic factor}} * \\ 25 \quad \text{OR}_{\text{exposure to only long working hours}})$$

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

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45 Of the 34,316 study participants (unweighted sample size = 27,927), 14,104 (41%)
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47 were female. We observed that 14.4% of Korean employees worked more than 52 hours per
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49 week (Table 1). Higher proportions of participants reporting long working hours were found
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51 among males (17%), older adults (24%), high school graduates (23%), and low–middle
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53 income (18%) workers. Regarding work-related variables, workers with temporary jobs
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(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		<i>p</i> -value
	<i>n</i>	Proportion	<i>n</i>	Proportion	<i>n</i>	Proportion	
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	10534	0.31	8115	0.77	8119	0.23	
school							
College or	21493	0.63	19450	0.90	2043	0.10	
more							
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–	7970	0.25	6555	0.82	1415	0.18	
middle							
High–	9365	0.29	7838	0.84	1528	0.16	
middle							
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							<0.001
risk factors							
Risk	8775	0.26	8069	0.27	707	0.14	
factors (–)							

Risk 25533 0.74 21292 0.73 4241 0.86

factors (+)

^aLong working hours (-): ≤ 30 and ≤ 52 hours

^bLong 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	<i>p</i> -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
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	OR (95% CI): <i>P</i>	OR (95% CI): <i>P</i>	vs. long working hours (+) ^b within strata of ergonomic risk factor OR (95% CI): <i>P</i>
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

^aLong working hours (-): ≤ 30 and ≤ 52 hours; ^bLong 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

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4 working hours and ergonomic risk factors. We observed a synergistic effect of the co-
5 exposure to long work hours and ergonomic risk factors on musculoskeletal symptoms that
6 was more detrimental than a simple addition of harmful effects by each exposure. As long
7 working hours imply prolonged exposure to ergonomic risk factors (e.g., repetitive tasks,
8 heavy lifting, and uncomfortable posture) and insufficient recovery, the interaction of long
9 working hours and ergonomic risk factors can lead to a higher risk of musculoskeletal
10 symptoms, compared with their simple additive effect. Several studies have suggested a dose-
11 response relationship between co-existing ergonomic risk factors, such as workload, lifting,
12 and awkward posture.[23–25] However, the results of this study suggest that the supra-
13 additive interaction between long working hours and ergonomic risk factors can worsen the
14 problem.

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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,

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4 are recommended to reduce musculoskeletal symptoms and the risk of developing
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6 musculoskeletal disorders.[28–31]
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9 This study had several limitations. First, it was a cross-sectional study; therefore,
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11 causality between exposure and musculoskeletal disorders could not be established because
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13 of the nature of the study design. However, when employees have musculoskeletal pain, they
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15 could not extend their working hours, owing to their symptoms. Therefore, the possibility of
16
17 a reverse causal relationship between long working hours and musculoskeletal symptoms is
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19 low. Second, the assessment of working hours and musculoskeletal symptoms was self-
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21 reported, which can lead to information bias. Third, this study did not consider other possible
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23 confounders, such as past medical history of injury, exercise, and body mass index, which
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25 could affect musculoskeletal symptoms. Fourth, we assessed musculoskeletal symptoms
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27 instead of musculoskeletal disorders. However, musculoskeletal symptoms are highly
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29 correlated with physical findings of musculoskeletal disorders as well as accompanying or
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31 preceding musculoskeletal diseases.[32, 33] Therefore, to prevent the occurrence of work-
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33 related musculoskeletal disorders, it makes sense to investigate the musculoskeletal
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35 symptoms in the workplace.
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43 In conclusion, the findings of this study suggest that long working hours combined
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45 with ergonomic risk factors can have harmful synergistic effects on musculoskeletal
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47 symptoms. The health of workers whom experience unfavorable working conditions,
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49 especially those concurrently exposed to ergonomic risk factors and long working hours,
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51 could be improved by reduced working hours and ergonomic improvement. Strict regulation
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53 of working hours and ergonomic intervention programs could help to prevent
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4 musculoskeletal disease in the workplace.
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8 **Acknowledgments**

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11 The authors sincerely appreciate the support of the Occupational Safety and Health Research
12
13 Institute (OSHRI) and the KOSHA for providing us with the raw data from the fifth KWCS.

14
15 This research is an important part of a thesis for a Master's degree of Jeong Woo Park from
16
17 the Graduate School of Dong-A University.
18
19

20 **Data Availability**

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23 Data are available in a public, open access repository KOSHA
24
25 (<https://www.kosha.or.kr/kosha/data/primitiveData.do>)
26
27
28

29 **Authors' Contributions**

30
31
32 **Seong-Sik Cho:** Conceptualization, formal analysis, methodology, writing—original draft,
33
34 writing—review & editing; **Jeong-Woo Park:** Writing—original draft, Writing—review &
35
36 editing; **Mo-Yeol Kang:** Writing—original draft **Jung-Il Kim:** Writing—review & editing;
37
38 **Jong-Hyun Hwang:** Writing—review & editing. All authors have read and agreed to the
39
40 published version of the manuscript.
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48 **Funding Statement**

49
50 This research is supported by the Dong-a University Research Fund [Grant Number: NA].
51
52 The funding body had no role to play in the study design, the collection, analysis and
53
54 interpretation of the data, the writing of the report, and the decision to submit the paper for
55
56
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4 publication.
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9 **Competing Interests Statement**

10 The authors declare no conflicts of interest.
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16 **Ethics Approval Statement:** The written informed consent and the review of the study was
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18 waived by the Institutional Review Board of Dong-A University Hospital (Approval No:
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20 DAUHIRB-TEMP-20-212).
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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) <i>Cohort study</i> —Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up <i>Case-control study</i> —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 <i>Cross-sectional study</i> —Give the eligibility criteria, and the sources and methods of selection of participants	5
		(b) <i>Cohort study</i> —For matched studies, give matching criteria and number of exposed and unexposed <i>Case-control study</i> —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) <i>Cohort study</i> —If applicable, explain how loss to follow-up was addressed <i>Case-control study</i> —If applicable, explain how matching of cases and controls was addressed <i>Cross-sectional study</i> —If applicable, describe analytical methods taking account of sampling strategy	7,8	
	(e) Describe any sensitivity analyses	NA	

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60**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) <i>Cohort study</i> —Summarise follow-up time (eg, average and total amount)	NA
Outcome data	15*	<i>Cohort study</i> —Report numbers of outcome events or summary measures over time	NA
		<i>Case-control study</i> —Report numbers in each exposure category, or summary measures of exposure	NA
		<i>Cross-sectional study</i> —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
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*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:	<i>BMJ Open</i>
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

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4 **Influence of co-exposure to long working hours and ergonomic risk factors on**
5 **musculoskeletal symptoms: An interaction analysis**
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Word Count (excluding title page, abstract, references, figures and tables): 2632words

For peer review only

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

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has a supra-additive interaction effect on musculoskeletal symptoms

For peer review only

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

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4 disorders, particularly using both additive and multiplicative scales. Thus, this study aimed to
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6 identify the combined effect of long working hours and ergonomic risk factors on
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8 musculoskeletal symptoms by interaction analysis on both additive and multiplicative scales.
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11 12 13 **METHODS**

14 15 **Study participants**

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17 We used a data sample from the fifth Korean Working Condition Survey (KWCS),
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19 conducted by the Korea Occupational Safety and Health Agency (KOSHA). The KWCS is
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21 comparable to the European Working Conditions Survey; it aims to survey the working
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23 conditions in various occupations. The sample from the fifth KWCS was recruited from 17
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25 cities and provinces in Korea and excludes individuals younger than 15 years.
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29 The target population included nationwide employed individuals aged 15 years or
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31 older in all Korean households in 2017. The survey was conducted through face-to-face
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33 interviews after obtaining consent from the participants. Students, stay-at-home spouses,
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35 unemployed, and retired individuals were excluded to ensure that the sample represented the
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37 economically active population. A sample design was constructed using a secondary
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39 probability proportion stratified cluster sample survey. Census districts were chosen based on
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41 the number of households. Thereafter, in each selected census district, ten households were
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43 randomly selected. Finally, one randomly selected eligible person in each household was
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45 interviewed (eligible persons were individuals employed at the point of the survey). The data
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47 of the fifth KWCS used design-weight to adjust the non-response rate and sample selection.
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49 In addition, the raking ratio method was used for post-stratification to adjust for the
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51 characteristics of gender, age, region, locality, and occupation.
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4 Of the total 50,205 employees (unweighted sample size = 50,205), 34,316 wage
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6 workers (unweighted sample size = 27,927)—excluding self-employed, unpaid family
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8 workers, and employers—were included in the analysis. Only employees whose weekly
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10 working hours totaled more than 30 hours were included to exclude the impact of incomplete
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12 employment.
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18 **Patient and public involvement**

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

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

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46 All study variables were collected from the KWCS questionnaire. Sociodemographic
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48 variables included gender, age, educational level, and income. Age was divided into five
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50 categories: <30, 30–39, 40–49, 50–59, ≥60. Education was classified according to three
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52 levels: middle school or less, high school graduate, or college or more. Monthly income was
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54 categorized into quartiles. Employment status was classified into three categories: regular,
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4 temporary, and daily. Shift work was classified into two categories (yes or no). The
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6 information about working hours per week was collected using the following question: “How
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8 many hours do you work per week?” Answers were divided into two categories: 30–52
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10 h/week was classed as “standard working hours,” while more than 52 h/week was classed as
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12 “long working hours.”
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16 Exposure to ergonomic risk factors was assessed using a questionnaire. First, the
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18 percentage of time that workers were exposed to a specific motion or posture during their
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20 working time was recorded. There were five items assessing ergonomic risk factors, namely
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22 tiring or painful position, lifting or moving people, carrying or moving heavy loads,
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24 continuous standing, and repetitive hand or arm movements.[4] For each item, the results
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26 were dichotomized into “with exposure” when the exposure time was half of the working
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28 hours or more per day, or “without exposure” when the exposure time was less than half of
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30 the working hours per day. Finally, if any of the five items were reported as “with exposure,”
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32 “ergonomic risk factor” was considered present, while if all five items were reported as
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34 “without exposure,” “ergonomic risk factor” was considered not present.
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40 Musculoskeletal symptoms were present when workers had any of the three
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42 following symptoms: neck and upper limb (shoulder, arm, elbow, wrist, hand) pain, lower
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44 limb (feet, knee, legs, hips) pain, or back pain during the last 12 months. Musculoskeletal
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46 symptoms were considered not present when workers had none of the three musculoskeletal
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48 problems (pain in neck and upper limb, lower limb, or back).
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52 53 **Statistical analysis**

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55 The characteristics of study participants (expressed in counts and proportions) were
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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;

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

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

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

In the epidemiologic study, if the RERI was greater than 0, it indicates there is a

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4 supra-additive interaction of two concurrent exposures. If the estimated ratio of the ORs was
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6 greater than 1, it indicates there is a supra-multiplicate interaction of two simultaneous
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8 exposures.[13]
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11 12 13 RESULTS

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15 Of the 34,316 study participants (unweighted sample size = 27,927), 14,104 (41%)
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17 were female. We observed that 14.4% of Korean employees worked more than 52 hours per
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19 week (Table 1). Higher proportions of participants reporting long working hours were found
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21 among males (17%), older adults (24%), high school graduates (23%), and low–middle
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23 income (18%) workers. Regarding work-related variables, workers with temporary jobs
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25 (20%) and shift work (23%) had the highest percentage of long working hours. In addition,
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27 workers who were exposed to ergonomic risk factors were more likely to report long working
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38 Table 1. Characteristics of study population

	Total		Long working hours (-) ^a		Long working hours (+) ^b		<i>p</i> -value
	<i>n</i>	Proportion	<i>n</i>	Proportion	<i>n</i>	Proportion	
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 (-)							
Risk	8775	0.26	8069	0.92	707	0.08	
Risk factors (+)							
Risk	25533	0.74	21292	0.83	4241	0.17	

^aLong working hours (-): ≤ 30 and ≤ 52 hours

^bLong 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		<i>p</i> -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

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

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4 Table 4 and figure 1 show the effect of the interaction between long working hours and
5 ergonomic risk factors on musculoskeletal symptoms. For long working hours without
6 ergonomic risk factors, the OR for musculoskeletal symptoms was 1.75 (95 % CI = 1.28–
7 1.39). For ergonomic risk factors without long working hours, the OR of musculoskeletal
8 symptoms was 3.49 (95% CI = 3.06–3.99). In addition, if workers were exposed to
9 simultaneous long working hours and ergonomic risk factors, the OR for musculoskeletal
10 symptoms was 5.07 (95% CI = 4.33–5.93). The RERI was 0.82 (95% CI = 0.11–1.53), and
11 the ratio of ORs was 0.83 (95% CI = 0.50–1.14). Thus, we observed a supra-additive
12 interaction between long working hours and ergonomic risk factors regarding their effect on
13 musculoskeletal symptoms
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30 Supplementary tables demonstrate the interaction between long working hours and heavy
31 load on back pain and between long working hours and painful position on neck and upper
32 limb pains. RERI for long working hours and heavy load on back pain was 0.98 (95%CI:
33 0.06-1.90), and RERI for long working hours and painful position on neck and upper limb
34 pains was 1.30 (95%CI: 0.53-2.06). This study observed supra-additive interactions between
35 long working hours and heavy load on back pain and between long working hours and
36 painful position on neck and upper limb pains.
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Table 4. Interaction effect of long working hours and ergonomic risk factors on musculoskeletal symptoms

	Long working hours (-) ^a OR (95% CI): <i>P</i>	Long working hours (+) ^b OR (95% CI): <i>P</i>	OR for long working hours (-) ^a vs. long working hours (+) ^b within strata of ergonomic risk factor OR (95% CI): <i>P</i>
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		

^aLong working hours (-): ≤30 and ≤52 hours; ^bLong 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

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4 lead to a higher risk of musculoskeletal symptoms, compared with their simple additive
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6 effect. Several studies have suggested a dose-response relationship between co-existing
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8 ergonomic risk factors, such as workload, lifting, and awkward posture.[24–26] However, the
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10 results of this study suggest that the supra-additive interaction between long working hours
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12 and ergonomic risk factors can worsen the problem.
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16 The current study proposed that stricter regulation of working hours is required. In
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18 2018, concerns over the long working hours of Korean workers led the government to limit
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20 the legal working hours to 52 hours or fewer per week. However, regulations on working
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22 hours are not strict and are applied only to large enterprises with 300 or more employees.[27]
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24 This means that employees in small-scale workplaces have a higher risk of working long
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26 hours.[28] In addition, it is well known that employees in small-scale workplaces work under
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28 unfavorable conditions more often than those in large-scale workplaces. Implementing legal
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30 systems prohibiting long working hours, especially more than 52 hours, may help reduce the
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32 prevalence of musculoskeletal symptoms, particularly among workers in small-scale
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34 workplaces. Moreover, working conditions should be improved. As such, multifocal
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36 ergonomic interventions programs, such as training in ergonomic principles, workstation
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38 modification (modifying working postures), surveying ergonomics, and exercise programs,
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40 are recommended to reduce musculoskeletal symptoms and the risk of developing
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42 musculoskeletal disorders.[29–32]
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48 This study had several limitations. First, it was a cross-sectional study; therefore,
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50 causality between exposure and musculoskeletal disorders could not be established because
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52 of the nature of the study design. However, when employees have musculoskeletal pain, they
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54 could not extend their working hours, owing to their symptoms. Therefore, the possibility of
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4 a reverse causal relationship between long working hours and musculoskeletal symptoms is
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6 low. Second, the assessment of working hours and musculoskeletal symptoms was self-
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8 reported, which can lead to information bias. Third, this study did not consider other possible
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10 confounders, such as past medical history of injury, exercise, and body mass index, which
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12 could affect musculoskeletal symptoms. Fourth, we assessed musculoskeletal symptoms
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14 instead of musculoskeletal disorders. However, musculoskeletal symptoms are highly
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16 correlated with physical findings of musculoskeletal disorders as well as accompanying or
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18 preceding musculoskeletal diseases.[33, 34] Therefore, to prevent the occurrence of work-
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20 related musculoskeletal disorders, it makes sense to investigate the musculoskeletal
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22 symptoms in the workplace.
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30 In conclusion, the findings of this study suggest that long working hours combined
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32 with ergonomic risk factors can have harmful synergistic effects on musculoskeletal
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34 symptoms. The health of workers who experience unfavorable working conditions, especially
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36 those concurrently exposed to ergonomic risk factors and long working hours, could be
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38 improved by reduced working hours and ergonomic improvement. Strict regulation of
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40 working hours and ergonomic intervention programs could be helpful to prevent
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42 musculoskeletal disease in the workplace.
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48 **Acknowledgments**

49
50 The authors sincerely appreciate the support of the Occupational Safety and Health Research
51
52 Institute (OSHRI) and the KOSHA for providing us with the raw data from the fifth KWCS.
53
54 This research is an important part of a thesis for a Master's degree of Jeong Woo Park from
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4 the Graduate School of Dong-A University.
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8 9 **Data Availability**

10 Data are available upon reasonable request.
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14 15 **Authors' Contributions**

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17 **Jeong-Woo Park:** Writing—original draft, Writing—review & editing; **Mo-Yeol Kang:**
18 Writing—review& editing; **Jung-Il Kim:** Writing—review & editing; **Jong-Hyun Hwang:**
19 Writing—review & editing; **Seong-Soo Choi:** Writing—review & editing; **Seong-Sik Cho:**
20 Conceptualization, formal analysis, methodology, writing—original draft, writing—review &
21 editing. All authors have read and agreed to the published version of the manuscript.
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32 33 **Funding**

34 This research is supported by the Dong-a University Research Fund. Funding is used for the
35 publication charge and English proofreading.
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41 42 **Competing Interests Statement**

43 The authors declare no conflicts of interest.
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48 **Ethics Approval Statement:** The written informed consent and the review of the study was
49 waived by the Institutional Review Board of Dong-A University Hospital (Approval No:
50 DAUHIRB-TEMP-20-212).
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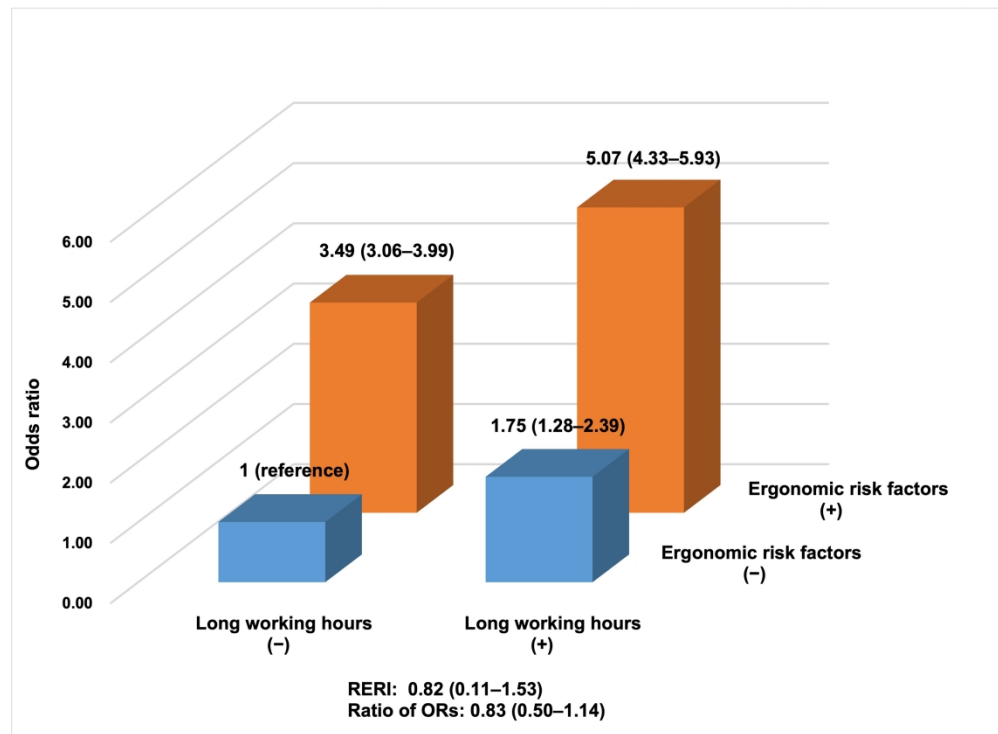
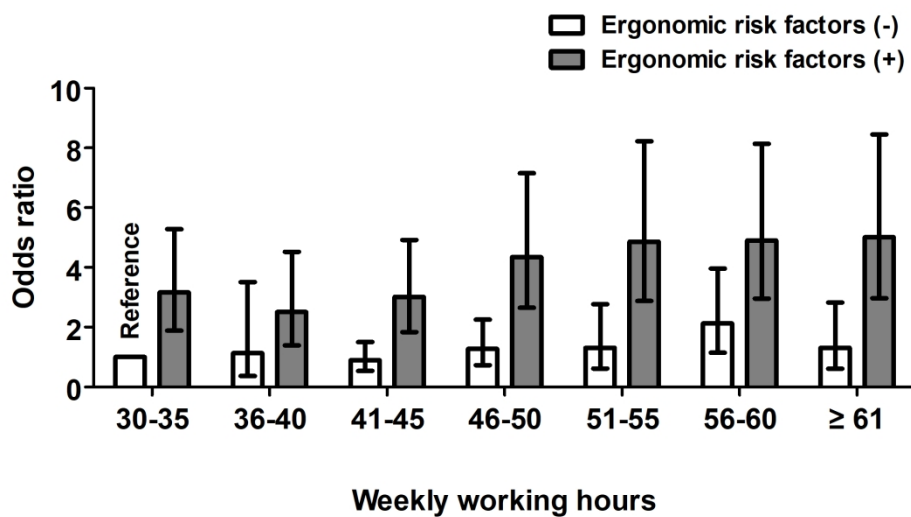


Figure 1. Combined effect of long working hours and ergonomic risk factors on musculoskeletal symptoms. Age, sex, education, income, employment, and shift work were adjusted in the model. RERI: relative excess risk due to interaction.

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	Long working hours (+) ^b	OR for long working hours (-) ^a vs. long working hours (+) ^b within strata of heavy load
	OR(95% CI): <i>P</i>	OR(95% CI): <i>P</i>	OR(95% CI): <i>P</i>
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		

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3 ^aLong working hours (-): ≤ 30 and ≤ 52 hours; ^bLong working hours (+): > 52 hours; OR: odds ratio; CI: confidence interval; RERI: relative
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excess risk due to interaction. Age, sex, education, income, employment, and shift work were adjusted for in the model.

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

	Long working hours (-) ^a	Long working hours (+) ^b	OR for long working hours (-) ^a vs. long working hours (+) ^b within strata of painful position
	OR(95% CI): <i>P</i>	OR(95% CI): <i>P</i>	OR (95% CI): <i>P</i>
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		

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6^aLong working hours (-): ≤ 30 and ≤ 52 hours; ^bLong working hours (+): > 52 hours; OR: odds ratio; CI: confidence interval; RERI: relative
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8 excess risk due to interaction. Age, sex, education, income, employment, and shift work were adjusted for in the model.
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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) <i>Cohort study</i> —Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up <i>Case-control study</i> —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 <i>Cross-sectional study</i> —Give the eligibility criteria, and the sources and methods of selection of participants	5
		(b) <i>Cohort study</i> —For matched studies, give matching criteria and number of exposed and unexposed <i>Case-control study</i> —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) <i>Cohort study</i> —If applicable, explain how loss to follow-up was addressed <i>Case-control study</i> —If applicable, explain how matching of cases and controls was addressed <i>Cross-sectional study</i> —If applicable, describe analytical methods taking account of sampling strategy	7,8	
	(e) Describe any sensitivity analyses	NA	

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60**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) <i>Cohort study</i> —Summarise follow-up time (eg, average and total amount)	NA
Outcome data	15*	<i>Cohort study</i> —Report numbers of outcome events or summary measures over time	NA
		<i>Case-control study</i> —Report numbers in each exposure category, or summary measures of exposure	NA
		<i>Cross-sectional study</i> —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
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*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:	<i>BMJ Open</i>
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

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4 **Influence of co-exposure to long working hours and ergonomic risk factors on**
5 **musculoskeletal symptoms: An interaction analysis**
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Word Count (excluding title page, abstract, references, figures and tables): 2801 words

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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

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

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4 disorders, particularly using both additive and multiplicative scales. Thus, this study aimed to
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6 identify the combined effect of long working hours and ergonomic risk factors on
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8 musculoskeletal symptoms by interaction analysis on both additive and multiplicative scales.
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11 12 13 **METHODS**

14 15 **Study participants**

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17 We used a data sample from the fifth Korean Working Condition Survey (KWCS),
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19 conducted by the Korea Occupational Safety and Health Agency (KOSHA). The KWCS is
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21 comparable to the European Working Conditions Survey; it aims to survey the working
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23 conditions in various occupations. The sample from the fifth KWCS was recruited from 17
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25 cities and provinces in Korea and excludes individuals younger than 15 years.
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29 The target population included nationwide employed individuals aged 15 years or
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31 older in all Korean households in 2017. The survey was conducted through face-to-face
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33 interviews after obtaining consent from the participants. Students, stay-at-home spouses,
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35 unemployed, and retired individuals were excluded to ensure that the sample represented the
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37 economically active population. A sample design was constructed using a secondary
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39 probability proportion stratified cluster sample survey. Census districts were chosen based on
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41 the number of households. Thereafter, in each selected census district, ten households were
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43 randomly selected. Finally, one randomly selected eligible person in each household was
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45 interviewed (eligible persons were individuals employed at the point of the survey). The data
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47 of the fifth KWCS used design-weight to adjust the non-response rate and sample selection.
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49 In addition, the raking ratio method was used for post-stratification to adjust for the
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51 characteristics of gender, age, region, locality, and occupation.
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4 Of the total 50,205 employees (unweighted sample size = 50,205), 34,316 wage
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6 workers (unweighted sample size = 27,927)—excluding self-employed, unpaid family
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8 workers, and employers—were included in the analysis. Only employees whose weekly
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10 working hours totaled more than 30 hours were included to exclude the impact of incomplete
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12 employment.
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18 **Patient and public involvement**

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20 Participants in the study were not involved in the design of the study. The raw data of
21
22 KWCS is available to the public. The study findings were only published in peer-reviewed
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24 journals, with no other information about the results provided to participants.
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30 **Ethical considerations**

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

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46 All study variables were collected from the KWCS questionnaire. Sociodemographic
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48 variables included gender, age, educational level, and income. Age was divided into five
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50 categories: <30, 30–39, 40–49, 50–59, ≥60. Education was classified according to three
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52 levels: middle school or less, high school graduate, or college or more. Monthly income was
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54 categorized into quartiles. Employment status was classified into three categories: regular,
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4 temporary, and daily. Shift work was classified into two categories (yes or no). The
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6 information about working hours per week was collected using the following question: “How
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8 many hours do you work per week?” Answers were divided into two categories: 30–52
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10 h/week was classed as “standard working hours,” while more than 52 h/week was classed as
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12 “long working hours.”
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16 Exposure to ergonomic risk factors was assessed using a questionnaire. First, the
17
18 percentage of time that workers were exposed to a specific motion or posture during their
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20 working time was recorded. There were five items assessing ergonomic risk factors, namely
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22 tiring or painful position, lifting or moving people, carrying or moving heavy loads,
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24 continuous standing, and repetitive hand or arm movements.[4] For each item, the results
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26 were dichotomized into “with exposure” when the exposure time was half of the working
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28 hours or more per day, or “without exposure” when the exposure time was less than half of
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30 the working hours per day. Finally, if any of the five items were reported as “with exposure,”
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32 “ergonomic risk factor” was considered present, while if all five items were reported as
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34 “without exposure,” “ergonomic risk factor” was considered not present.
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40 Musculoskeletal symptoms were present when workers had any of the three
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42 following symptoms: neck and upper limb (shoulder, arm, elbow, wrist, hand) pain, lower
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44 limb (feet, knee, legs, hips) pain, or back pain during the last 12 months. Musculoskeletal
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46 symptoms were considered not present when workers had none of the three musculoskeletal
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48 problems (pain in neck and upper limb, lower limb, or back).
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52 53 **Statistical analysis**

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55 The characteristics of study participants (expressed in counts and proportions) were
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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;

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

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

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

In the epidemiologic study, if the RERI was greater than 0, it indicates there is a

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4 supra-additive interaction of two concurrent exposures. If the estimated ratio of the ORs was
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6 greater than 1, it indicates there is a supra-multiplicate interaction of two simultaneous
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8 exposures.[13]
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11 12 13 RESULTS

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15 Of the 34,316 study participants (unweighted sample size = 27,927), 14,104 (41%)
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17 were female. We observed that 14.4% of Korean employees worked more than 52 hours per
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19 week (Table 1). Higher proportions of participants reporting long working hours were found
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21 among males (17%), older adults (24%), high school graduates (23%), and low–middle
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23 income (18%) workers. Regarding work-related variables, workers with temporary jobs
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25 (20%) and shift work (23%) had the highest percentage of long working hours. In addition,
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27 workers who were exposed to ergonomic risk factors were more likely to report long working
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29 hours.
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38 Table 1. Characteristics of study population

	Total		Long working hours (-) ^a		Long working hours (+) ^b		<i>p</i> -value
	<i>n</i>	Proportion	<i>n</i>	Proportion	<i>n</i>	Proportion	
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 (-)							
Risk	8775	0.26	8069	0.92	707	0.08	
Risk factors (+)							
Risk	25533	0.74	21292	0.83	4241	0.17	

^aLong working hours (-): ≤ 30 and ≤ 52 hours

^bLong 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		<i>p</i> -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.

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

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4 Table 4 and figure 1 show the effect of the interaction between long working hours and
5 ergonomic risk factors on musculoskeletal symptoms. For long working hours without
6 ergonomic risk factors, the OR for musculoskeletal symptoms was 1.75 (95 % CI = 1.28–
7 1.39). For ergonomic risk factors without long working hours, the OR of musculoskeletal
8 symptoms was 3.49 (95% CI = 3.06–3.99). In addition, if workers were exposed to
9 simultaneous long working hours and ergonomic risk factors, the OR for musculoskeletal
10 symptoms was 5.07 (95% CI = 4.33–5.93). The RERI was 0.82 (95% CI = 0.11–1.53), and
11 the ratio of ORs was 0.83 (95% CI = 0.50–1.14). Thus, we observed a supra-additive
12 interaction between long working hours and ergonomic risk factors regarding their effect on
13 musculoskeletal symptoms
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30 Supplementary tables demonstrate the interaction between long working hours and heavy
31 load on back pain and between long working hours and painful position on neck and upper
32 limb pains. RERI for long working hours and heavy load on back pain was 0.98 (95%CI:
33 0.06-1.90), and RERI for long working hours and painful position on neck and upper limb
34 pains was 1.30 (95%CI: 0.53-2.06). This study observed supra-additive interactions between
35 long working hours and heavy load on back pain and between long working hours and
36 painful position on neck and upper limb pains.
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Table 4. Interaction effect of long working hours and ergonomic risk factors on musculoskeletal symptoms

	Long working hours (-) ^a OR (95% CI): <i>P</i>	Long working hours (+) ^b OR (95% CI): <i>P</i>	OR for long working hours (-) ^a vs. long working hours (+) ^b within strata of ergonomic risk factor OR (95% CI): <i>P</i>
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		

^aLong working hours (-): ≤30 and ≤52 hours; ^bLong 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

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4 addition of harmful effects by each exposure. As seen in supplementary tables, similar supra-
5
6 additive interactions were observed in long working hours and heavy load on back pain, and
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8 long working hours and painful position on the neck and upper limbs. This finding is
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10 consistent with the results of table 4. This result may support the main hypothesis of the
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12 study.
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16 As long working hours imply prolonged exposure to ergonomic risk factors (e.g.,
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18 repetitive tasks, heavy lifting, and uncomfortable posture) and insufficient recovery, the
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20 interaction of long working hours and ergonomic risk factors can lead to a higher risk of
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22 musculoskeletal symptoms, compared with their simple additive effect. Several studies have
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24 suggested a dose-response relationship between co-existing ergonomic risk factors, such as
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26 workload, lifting, and awkward posture.[24–26] However, the results of this study suggest
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28 that the supra-additive interaction between long working hours and ergonomic risk factors
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30 can worsen the problem.
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34 The current study proposed that stricter regulation of working hours is required. In
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36 2018, concerns over the long working hours of Korean workers led the government to limit
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38 the legal working hours to 52 hours or fewer per week. However, regulations on working
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40 hours are not strict and are applied only to large enterprises with 300 or more employees.[27]
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42 This means that employees in small-scale workplaces have a higher risk of working long
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44 hours.[28] In addition, it is well known that employees in small-scale workplaces work under
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46 unfavorable conditions more often than those in large-scale workplaces. Implementing legal
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48 systems prohibiting long working hours, especially more than 52 hours, may help reduce the
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50 prevalence of musculoskeletal symptoms, particularly among workers in small-scale
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52 workplaces. Moreover, working conditions should be improved. As such, multifocal
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4 ergonomic interventions programs, such as training in ergonomic principles, workstation
5 modification (modifying working postures), surveying ergonomics, and exercise programs,
6 are recommended to reduce musculoskeletal symptoms and the risk of developing
7 musculoskeletal disorders.[29–32]
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13 This study had several limitations. First, it was a cross-sectional study; therefore,
14 causality between exposure and musculoskeletal disorders could not be established because
15 of the nature of the study design. However, when employees have musculoskeletal pain, they
16 could not extend their working hours, owing to their symptoms. Therefore, the possibility of
17 a reverse causal relationship between long working hours and musculoskeletal symptoms is
18 low. Second, the assessment of working hours and musculoskeletal symptoms was self-
19 reported, which can lead to information bias. Third, this study did not consider other possible
20 confounders, such as past medical history of injury, exercise, and body mass index, which
21 could affect musculoskeletal symptoms. Fourth, we assessed musculoskeletal symptoms
22 instead of musculoskeletal disorders. However, musculoskeletal symptoms are highly
23 correlated with physical findings of musculoskeletal disorders as well as accompanying or
24 preceding musculoskeletal diseases.[33, 34] Therefore, to prevent the occurrence of work-
25 related musculoskeletal disorders, it makes sense to investigate the musculoskeletal
26 symptoms in the workplace.
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48 In conclusion, the findings of this study suggest that long working hours combined
49 with ergonomic risk factors can have harmful synergistic effects on musculoskeletal
50 symptoms. The health of workers who experience unfavorable working conditions, especially
51 those concurrently exposed to ergonomic risk factors and long working hours, could be
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4 improved by reduced working hours and ergonomic improvement. Strict regulation of
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6 working hours and ergonomic intervention programs could be helpful to prevent
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8 musculoskeletal disease in the workplace.
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11 12 13 **Acknowledgments**

14
15 This research is supported by the Dong-a University Research Fund. Funding is used for the
16
17 publication charge and English proofreading. This research is an important part of a thesis for
18
19 a Master's degree of Jeong Woo Park from the Graduate School of Dong-A University.
20
21

22 The authors sincerely appreciate the support of the Occupational Safety and Health Research
23
24 Institute (OSHRI) and the KOSHA for providing us with the raw data from the fifth KWCS.
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29 **Data Availability**

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31 Data are available upon reasonable request.
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36 **Authors' Contributions**

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38 **Jeong-Woo Park:** Writing—original draft, Writing—review & editing; **Mo-Yeol Kang:**
39
40 Writing—review& editing; **Jung-II Kim:** Writing—review & editing; **Jong-Hyun Hwang:**
41
42 Writing—review & editing; **Seong-Soo Choi:** Writing—review & editing; **Seong-Sik Cho:**
43
44 Conceptualization, formal analysis, methodology, writing—original draft, writing—review &
45
46 editing. All authors have read and agreed to the published version of the manuscript.
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52 **Competing Interests Statement**

53
54 The authors declare no conflicts of interest.
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4 **Ethics Approval Statement:** The written informed consent and the review of the study was
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6 waived by the Institutional Review Board of Dong-A University Hospital (Approval No:
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4 Figure 1. Combined effect of long working hours and ergonomic risk factors on
5 musculoskeletal symptoms. Age, sex, education, income, employment, and shift work
6 adjusted in the model. RERI : relative excess risk due to interaction.
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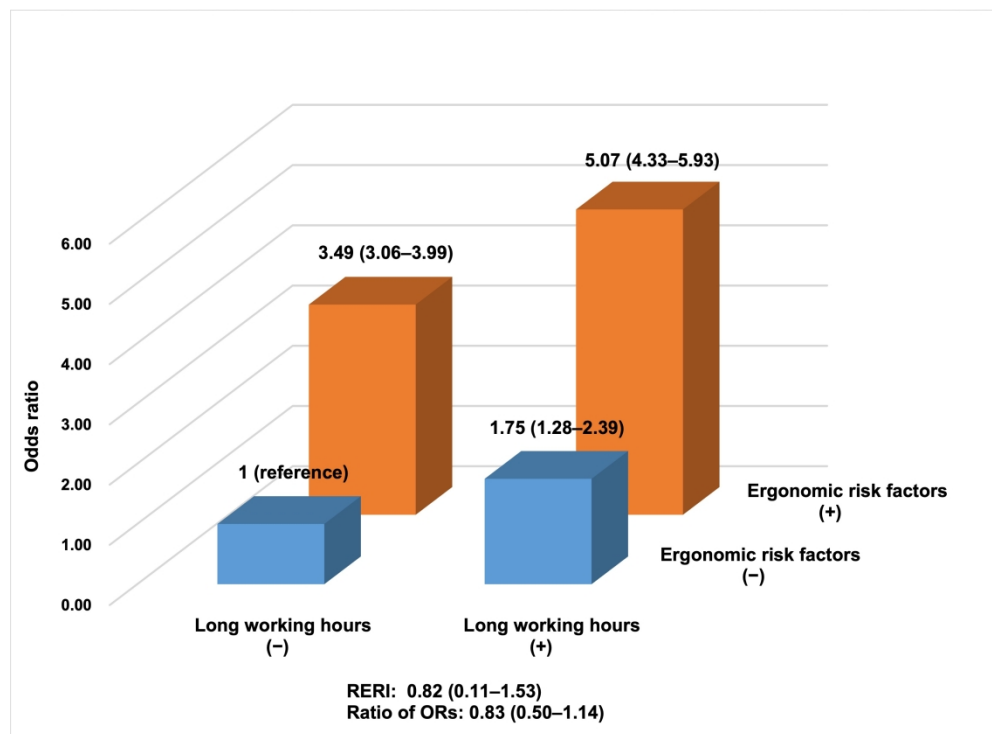
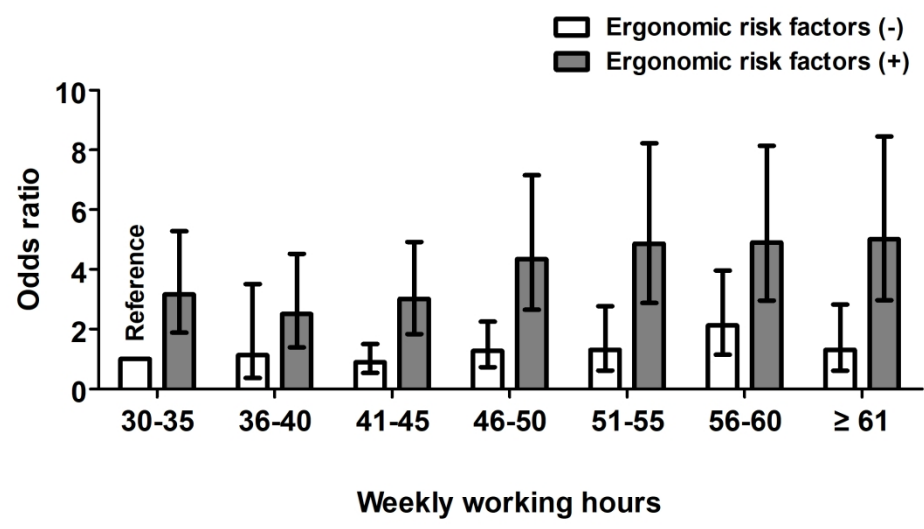


Figure 1. Combined effect of long working hours and ergonomic risk factors on musculoskeletal symptoms. Age, sex, education, income, employment, and shift work were adjusted in the model. RERI: relative excess risk due to interaction.



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.

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

	Long working hours (-) ^a	Long working hours (+) ^b	OR for long working hours (-) ^a vs. long working hours (+) ^b within strata of heavy load OR(95% CI): <i>P</i>
	OR(95% CI): <i>P</i>	OR(95% CI): <i>P</i>	
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		

^aLong working hours (-): ≤ 30 and ≤ 52 hours; ^bLong 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.

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

	Long working hours (-) ^a	Long working hours (+) ^b	OR for long working hours (-) ^a vs. long working hours (+) ^b within strata of painful position
	OR(95% CI): <i>P</i>	OR(95% CI): <i>P</i>	OR (95% CI): <i>P</i>
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		

^aLong working hours (-): ≤ 30 and ≤ 52 hours; ^bLong 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.

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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) <i>Cohort study</i> —Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up <i>Case-control study</i> —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 <i>Cross-sectional study</i> —Give the eligibility criteria, and the sources and methods of selection of participants	5
		(b) <i>Cohort study</i> —For matched studies, give matching criteria and number of exposed and unexposed <i>Case-control study</i> —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) <i>Cohort study</i> —If applicable, explain how loss to follow-up was addressed <i>Case-control study</i> —If applicable, explain how matching of cases and controls was addressed <i>Cross-sectional study</i> —If applicable, describe analytical methods taking account of sampling strategy	7,8
		(e) Describe any sensitivity analyses	NA

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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) <i>Cohort study</i> —Summarise follow-up time (eg, average and total amount)	NA
Outcome data	15*	<i>Cohort study</i> —Report numbers of outcome events or summary measures over time	NA
		<i>Case-control study</i> —Report numbers in each exposure category, or summary measures of exposure	NA
		<i>Cross-sectional study</i> —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.