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# Physical workload and bodily fatigue after work: cross-sectional study among 5000 workers

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**Background:** Persistent bodily fatigue after working days may indicate an imbalance between work demands and capacity of the workers. This study aimed to investigate associations between physical exposures at work and bodily fatigue after work. **Methods:** Danish workers with physical work ( $N=5377$ ) answered questions about various physical exposures during work and bodily fatigue after work in the 2010 round of the Danish Work Environment Cohort Study. Associations were modeled using binary logistic regression controlled for various confounders. **Results:** Mean age among the younger ( $<50$  years) and older ( $\geq 50$  years) workers was 36 and 56 years, respectively. Younger and older workers exposed to various physical exposures (e.g. 'bending/twisting the back') for more than a quarter of the workday were more fatigued after work. An exposure–response relationship was observed between the number of physical exposures and bodily fatigue, with odds ratios (OR) for fatigue in the body among younger workers being 1.01 (95%CI 0.63–1.63), 1.59 (95%CI 1.01–2.50), 2.37 (95%CI 1.54–3.66) and 2.84 (95%CI 1.85–5.36) for 1, 2, 3 and  $\geq 4$  types of combined physical exposures, respectively. Correspondingly, for older workers, ORs were 1.95 (95%CI 1.09–3.51), 4.06 (95%CI 2.32–7.12), 4.10 (95%CI 2.28–7.37) and 4.90 (95%CI 2.72–8.82) for 1, 2, 3 and  $\geq 4$  exposures, respectively. **Conclusion:** While some of the single factor exposures were associated with increased bodily fatigue, the most marked associations were found when summing the number of different exposures. These results indicate that workplaces should focus on the sum of combined physical exposures rather than focusing solely on single exposures.

## Introduction

Fatigue after work is commonly experienced by workers engaged in physical work<sup>1</sup> and is defined as a feeling of tiredness, lack of energy and exhaustion.<sup>2</sup> Fatigue can affect both physical and cognitive functioning.<sup>2</sup> In the Danish Work Environment Cohort Study (DWECS) conducted in 2016 among the general working population, 66% felt somewhat tired to completely exhausted after a workday.<sup>1</sup> Additionally, in a national random-digital-dial telephone survey among a random sample of US workers, 38% experienced a lack of energy, poor sleep and fatigue in the past 2 weeks.<sup>3</sup> That study had a sampling frame of 28 902 workers and reported that the health-related and economic consequences of fatigue in workers are enormous and that fatigued workers cost employers \$101.0 billion annually more than non-fatigued workers in health-related lost productive time.<sup>3</sup> The US study used a computer-assisted telephone data collection instrument that calculates lost productive time based on answers on e.g. occupational status, health conditions, lifestyle factors and demographic characteristics.<sup>3</sup> Lost productive time was calculated as a sum of self-reported absence from work due to health-reasons and self-reported reduced performance at work due to health-reasons.<sup>3</sup>

Physical work is inherently associated with a higher level of physical exertion than sedentary work<sup>4,5</sup> and has been associated with increased risk of long-term sickness absence, premature exit from the labor market and even earlier death.<sup>6–9</sup> Moreover, associations have been observed between physical exposures at work in specific body regions and development of musculoskeletal disorders, indicating that physical work particularly affects the exposed body regions.<sup>10</sup> Physical exposures such as bending or twisting the back, working with arms at or above

shoulder height, pushing/pulling/lifting/carrying, squatting or kneeling, neck flexion, repetitive hand/arm movement and standing in the same place have been found predictive of long-term sickness absence and musculoskeletal pain and disorders.<sup>6,8,10–13</sup>

It may be speculated that physical work affects older workers more than young workers because physical capacity inherently declines with age.<sup>14,15</sup> Due to demographic changes in many Western societies, the population is aging, and reforms are passed to gradually increase statutory retirement age in many countries. As physical capacity in terms of strength and power declines with age due to loss of muscle fibers and muscle fiber atrophy,<sup>15</sup> physical work may be more fatiguing for older workers. However, the 2016 round of the Work Environment & Health study, revealed that older workers perceive their work to be less physically demanding compared to younger workers, and older workers were not more fatigued after work than their younger counterparts.<sup>1</sup> Thus, this study aimed to investigate the association between various physical exposures during work with bodily fatigue after work in young ( $<50$  years) and old workers ( $\geq 50$  years) with physical work. We hypothesized that being exposed to an increased number of physical exposures during work would be associated—in an exposure-response fashion—with increased bodily fatigue in general as well as fatigue in the exposed body regions in both younger and older workers.

## Methods

### Study design

This cross-sectional study employed data from the 2010 round of the DWECS.<sup>16</sup> DWECS comprises questionnaires on work environment

and health among the general working population in Denmark. The specific questions used for this study are specified below. The reporting of the study follows the guidelines for observational studies 'Strengthening in the Reporting of Observational Studies in Epidemiology'.<sup>17</sup>

### Ethics

This study has been reported to and registered by the Danish Data Protection Agency (journal number 2015-57-0074). Neither approval by ethical and scientific committees, nor informed consent, are needed in questionnaires and register-based studies according to the Danish law.<sup>18</sup> All data were de-identified and analyzed anonymously.

### Participants

A sample of 20 000 adult Danish workers  $\geq 18$  years received the questionnaire and the response percentage was 53% (10 605 workers).<sup>19,20</sup> The participants were drawn from the Central Population Register of Denmark and this study included only workers with physical work tasks ( $N = 5377$ ). Based on the answer to the following question 'How will you describe your physical activity level in your main profession?', participants were classified as having physical work when replying positively to one of the following questions: (i) 'Mostly standing and walking work that otherwise is not physically demanding', (ii) 'Standing or walking work with some lifting- and bearing tasks' (3) 'Heavy or fast work that is physically demanding'.<sup>21</sup> Participants who replied 'Mostly sedentary work that is not physically demanding' were excluded from the analyses. Because not all participants filled in all survey questions, the exact number of participants for each analysis varies. Demographics and lifestyle characteristics of the study sample are reported in table 1.

### Explanatory variables

#### Physical exposure during work

To determine the physical exposure during the work, participants answered the following questions: 'Does your work cause you to: (i) stand in the same place, (ii) work with your back strongly bent

forward without hand- and arm support, (iii) twist and bend your back several times per hour, (iv) have your arms raised to or above shoulder height, (v) perform the same arm movements several times per minute (e.g. package work, mounting, machine feeding, carving), (vi) squat or kneel, (vii) push or pull (viii) carry or lift?'. For further analyses, questions 7 and 8 were collapsed. The response options to all questions were: '1) Almost all the time, 2) Approximately 3/4 of the time, 3) Approximately 1/2 of the time, 4) Approximately 1/4 of the time, 5) Rarely/very little, or 6) Never'.<sup>6</sup> These categories were defined as 100, 75, 50, 25, 12½ and 0% of the total duration of the workday, respectively. Cut-points for the duration of the workday exposed to all physical exposures were set to 25% of the workday, except for 'standing in the same place', which was set to 50% of the workday. These cut-points were based on a previously published article that found significant associations with sickness absence at these cut-points.<sup>6</sup>

### Outcome variable

#### Fatigue after work

To detect physical fatigue after a workday, participants answered the following questions: 'How physically tired are you after a typical day at work in your: 1) body in general, 2) back, 3) neck/shoulders, 4) arms/wrists, and 5) legs?'.<sup>22</sup> Response options were: '1) Not tired, 2) A little tired, 3) Somewhat tired, 4) Very tired, and 5) Completely exhausted'.

### Control variables

The analyses were controlled for age (years, continuous), body mass index (BMI) ( $\text{kg}/\text{m}^2$ , continuous), psychosocial work factors (single items on emotional demands and influence at work from the Copenhagen Psychosocial Questionnaire<sup>23</sup>) (continuous scale, 0–100), job group (categorical), gender ('male' or 'female'), smoking status ('No, never', 'Ex-smoker', or 'Yes') and chronic disease (categorical). The reason for controlling for these were that previous studies have found associations of psychosocial working conditions,<sup>24</sup> age,<sup>3,14</sup> chronic diseases<sup>3</sup> and smoking<sup>24</sup> with fatigue or being physically tired after work. Status of chronic disease was determined by the question 'Have a doctor ever informed you that you have one or more of the following diseases?': 'depression', 'asthma', 'diabetes (all types)', 'cardiovascular disease', 'cancer' and 'back disease'. The response options were 'Yes' and 'No, never'.

### Statistics

Statistical analyses were conducted using the SAS statistical software for Windows (Proc Logistic, SAS version 9.4, SAS Institute, Cary, NC). The probability of being very tired (options 'very tired' and 'completely exhausted' collapsed) compared with a little tired (options 'not tired', 'a little tired' and 'somewhat tired' collapsed) was modeled using binary logistic regression controlled for the aforementioned variables. Fisher's scoring was used as optimization technique. Estimates are provided as OR and 95% confidence intervals (CI).

### Results

The percentage of male and female workers in the younger age-group was 44.7 and 55.3%, respectively (table 1). Among older workers, 47.2% were male, while 52.9% were female. The mean age for the young and older workers, respectively, was 36 and 56 years.

Associations between physical exposure during work and fatigue after work among younger and older workers are reported in tables 2 and 3, respectively. Working with bended/twisted back more than a quarter of a work day was associated with increased level of fatigue in the body in general and in various body sections in both younger

**Table 1** Demographics and lifestyle characteristics

	<50 years			$\geq 50$ years		
	N	Mean (SD)	%	N	Mean (SD)	%
Participants	3483			1894		
Age, years		36.1 (9.4)			55.6 (3.7)	
Gender						
Men	1558		44.7	893		47.2
Women	1925		55.3	1001		52.9
BMI						
Underweight	36		1.1	10		0.5
Normal	1825		54.5	840		45.3
Overweight	1044		31.2	723		39.0
Obese	447		13.3	282		15.2
Smoking						
Yes	895		26.5	520		27.8
Ex-smoker	760		22.5	696		37.2
No	1717		50.9	657		35.1
Physical activity at work						
Mostly standing or walking	1541		44.2	884		46.7
Standing or walking with lifting/bearing tasks	1584		45.5	872		46.0
Heavy or fast work	358		10.3	138		7.3

BMI: body mass index.

**Table 2** Associations between physical exposures during work and fatigue after work in the body in general and in specific body regions among workers <50 years with physically demanding works

Exposures	N	%	% of work time	Body in general OR (95% CI)	Back OR (95% CI)	Neck/shoulders OR (95% CI)	Arms/wrists OR (95% CI)	Legs OR (95% CI)
Standing in the same place	2807	83	0–25	1	1	1	1	1
	575	17	50–100	1.16 (0.82–1.63)	0.90 (0.62–1.32)	1.18 (0.84–1.66)	1.13 (0.75–1.72)	<b>1.55 (1.13–2.13)</b>
Bending/twisting the back	1559	45.9	0–12.5	1	1	1	1	1
	1840	54.1	25–100	<b>1.86 (1.33–2.59)</b>	<b>3.09 (2.09–4.58)</b>	<b>2.03 (1.47–2.82)</b>	1.34 (0.89–2.03)	<b>2.03 (1.48–2.78)</b>
Arms at or above shoulder height	2484	73.2	0–12.5	1	1	1	1	1
	908	26.8	25–100	1.22 (0.90–1.65)	1.20 (0.87–1.65)	1.26 (0.94–1.69)	1.39 (0.97–2.01)	1.24 (0.93–1.65)
Repetitive arm movement	2413	71.8	0–12.5	1	1	1	1	1
	948	28.2	25–100	<b>1.46 (1.07–1.99)</b>	<b>1.52 (1.10–2.11)</b>	<b>1.85 (1.37–2.52)</b>	<b>1.86 (1.28–2.70)</b>	1.25 (0.94–1.68)
Squatting or kneeling	2424	72.6	0–12.5	1	1	1	1	1
	914	27.4	25–100	1.00 (0.73–1.37)	1.08 (0.77–1.51)	1.14 (0.84–1.54)	0.91 (0.62–1.35)	1.00 (0.74–1.35)
Lifting/carrying or pushing/pulling	1476	43.3	0–12.5	1	1	1	1	1
	1935	56.7	25–100	1.15 (0.83–1.59)	<b>1.50 (1.03–2.19)</b>	1.29 (0.93–1.78)	<b>1.61 (1.05–2.46)</b>	1.24 (0.90–1.69)

Notes: Cut-points for physical exposure were set at 25% of work time, except 'Standing in the same place', which was set at 50% of work time. Risk estimates are given as OR and 95% CI. Significant differences ( $P < 0.05$ ) from reference are marked in bold.

and older workers. Repetitive arm movements more than a quarter of a workday was associated with increased fatigue in the body in general and in various body parts among younger workers, while this was not observed for older workers. Standing in the same place for more than half of the workday was associated with fatigue in various body segments among older workers, while same exposure only associated with increased fatigue in the legs among younger workers. Additionally, neither working with arms at or above shoulder height nor squatting or kneeling more than a quarter of the work time was associated with increased fatigue after work in neither younger nor older workers (tables 2 and 3).

Table 4 reports associations between the summed number of combined physical exposures more than a quarter of the work time and bodily fatigue after work. The results show an exposure–response relationship between increased number of combined physical exposures during work and fatigue in the body in general and in various body regions after work in both younger and older workers (trend test  $P < 0.0001$ ). Overall, two or more physical exposures during work associated with increased fatigue after work in both younger and older workers, except for fatigue in arms and wrists among young workers, where only four or more physical exposures significantly associated with increased fatigue in arms and wrists. For example, among older workers, being exposed to one physical exposure during work resulted in ORs of 1.95 (95%CI 1.09–3.51) for being fatigued after work, whereas older workers exposed to  $\geq 4$  exposures resulted in ORs of 4.90 (95%CI 2.72–8.82) for being fatigued after work.

## Discussion

The main finding of this study is the exposure–response relationship between increased number of physical exposures during work and bodily fatigue after work. Additionally, physical exposures during work—such as 'standing in the same place', 'bending/twisting the back' and 'repetitive arm movement'—are associated with increased self-reported fatigue, and the specific physical exposures associated with fatigue may not be the same for younger and older workers.

First, the method of defining 'physical exposure' needs to be discussed. The cut-points for time exposed to various physical exposures at work in this study—i.e. 25% of the work time, except for 'standing in the same place' which was 50% of the work time—were based on previous findings from the DWECs study.<sup>6</sup> Andersen and co-workers found a significantly increased risk for long-term sickness absence when workers were exposed to various physical exposures for a quarter of the work time, and when workers were standing in the same place for more than half of the work time.<sup>6</sup> Moreover, Sterud also dichotomized the cut-points into

quartiles.<sup>8</sup> As those two studies found bending/twisting the back to be a strong risk factor for long-term sickness absence, our study elaborates on these findings by demonstrating the strongest associations between working with bended/twisted back and bodily fatigue after work in both younger and older workers, with ORs of 3.09 (95%CI 2.09–4.58) for fatigue in the back among younger workers and ORs of 2.59 (95%CI 1.62–4.14) for fatigue in the back in older workers. However, exceeding a quarter of the workday bending/twisting the back also resulted in higher odds for fatigue in the body in general, neck/shoulders and legs in younger workers with ORs of 1.86 (95%CI 1.33–2.59), 2.03 (95%CI 1.47–2.82) and 2.03 (95%CI 1.48–2.78), respectively. In older workers, same physical exposures resulted in ORs of 2.51 (95%CI 1.68–3.76), 1.85 (95%CI 1.26–2.71) and 1.66 (95%CI 1.05–2.62) for experiencing fatigue in the body in general, neck/shoulders and arms/wrist, respectively. Other physical exposures also associated with fatigue after work, i.e. repetitive arm movements, lifting/carrying or pushing/pulling and standing in the same place, with differences in associations between age-groups. Hence, it seems as physical exposures at work affect younger and older workers differently, where younger workers experience most fatigue from working with bended/twisted back and repetitive arm movements, while older workers showed largest associations with bending/twisting the back and standing in the same place.

Our results also show an exposure–fatigue specificity as physical exposures are associated with fatigue specifically in the exposed body regions. For example, in younger workers, repetitive arm movements are associated with fatigue in the body in general, the back, neck/shoulders and arms/wrists, but not in the legs. Moreover, a lower percentage of older workers are exposed to the physical exposures included in this study compared to the younger workers. Besides a selection bias where the included older workers can cope with their work and therefore still are working (healthy worker effect), this may indicate that older workers get different and lighter work tasks with increased age. This corresponds with the DWECs 2016 report where older workers seem to be less exposed to various physical exposures at work and be less fatigued after work than younger workers.<sup>1</sup>

Physical work often comprises exposure to several demanding work tasks. To provide a more comprehensive picture of physical work we, therefore, calculated associations between summed number of physical exposures at work and bodily fatigue after work.<sup>6</sup> In the analyses we observed strong associations in younger workers being exposed to two physical exposures at work and being fatigued in the back after work, with ORs of 3.27 (95%CI 1.83–5.85). Conversely, older workers with only one physical exposure had ORs of 2.06 (95%CI 1.09–3.90) for being fatigued in the back after work,



**Table 3** Associations between physical exposures during work and fatigue after work in the body in general and in specific body regions among workers  $\geq 50$  years with physically demanding works

Exposures	N	%	% of work time	Body in general OR (95% CI)	Back OR (95% CI)	Neck/shoulders OR (95% CI)	Arms/wrists OR (95% CI)	Legs OR (95% CI)
Standing in the same place	1572	86.7	0–25	1	1	1	1	1
	242	13.3	50–100	1.16 (0.69–1.93)	1.57 (0.90–2.72)	<b>1.66 (1.03–2.67)</b>	<b>1.77 (1.04–3.03)</b>	<b>1.98 (1.25–3.13)</b>
Bending/twisting the back	928	50.3	0–12.5	1	1	1	1	1
	918	49.7	25–100	<b>2.51 (1.68–3.76)</b>	<b>2.59 (1.62–4.14)</b>	<b>1.85 (1.26–2.71)</b>	<b>1.66 (1.05–2.62)</b>	1.23 (0.85–1.78)
Arms at or above shoulder height	1417	77.4	0–12.5	1	1	1	1	1
	415	22.7	25–100	0.86 (0.57–1.30)	0.95 (0.60–1.50)	1.22 (0.82–1.83)	0.94 (0.59–1.50)	1.37 (0.93–2.02)
Repetitive arm movement	1407	77.0	0–12.5	1	1	1	1	1
	421	23.0	25–100	1.04 (0.67–1.61)	1.56 (0.97–2.52)	1.33 (0.87–2.03)	<b>2.96 (1.86–4.70)</b>	1.09 (0.72–1.63)
Squatting or kneeling	1469	80.5	0–12.5	1	1	1	1	1
	356	19.5	25–100	1.42 (0.94–2.16)	1.14 (0.71–1.83)	1.04 (0.69–1.58)	1.18 (0.74–1.91)	1.07 (0.71–1.61)
Lifting/carrying or pushing/pulling	913	49.4	0–12.5	1	1	1	1	1
	934	50.6	25–100	<b>1.55 (1.04–2.32)</b>	1.09 (0.69–1.73)	1.28 (0.87–1.89)	0.91 (0.58–1.42)	<b>1.72 (1.18–2.51)</b>

Notes: Cut-points for physical exposure were set at 25% of work time, except 'Standing in the same place', which was set at 50% of work time. Risk estimates are given as OR and 95% CI. Significant differences ( $P < 0.05$ ) are marked in bold.

**Table 4** Summed number of physical exposures during work and fatigue after work in various body regions

Number of exposures stratified by age	N	%	Body in general OR (95% CI)	Back OR (95% CI)	Neck/shoulders OR (95% CI)	Arms/wrists OR (95% CI)	Legs OR (95% CI)
<b>&lt;50 years</b>							
0	817	23.8	1	1	1	1	1
1	631	18.4	1.01 (0.63–1.63)	1.32 (0.70–2.48)	1.43 (0.88–2.33)	1.14 (0.60–2.17)	1.28 (0.80–2.04)
2	582	17.0	<b>1.59 (1.01–2.50)</b>	<b>3.27 (1.83–5.85)</b>	<b>2.74 (1.72–4.36)</b>	1.65 (0.90–3.03)	<b>2.00 (1.27–3.13)</b>
3	609	17.8	<b>2.37 (1.54–3.66)</b>	<b>4.86 (2.79–8.47)</b>	<b>3.25 (2.06–5.12)</b>	1.54 (0.84–2.81)	<b>2.29 (1.48–3.56)</b>
$\geq 4$	788	23.0	<b>2.84 (1.85–5.36)</b>	<b>6.29 (3.63–10.89)</b>	<b>5.90 (3.78–9.23)</b>	<b>3.83 (2.18–6.73)</b>	<b>3.49 (2.28–5.34)</b>
<b><math>\geq 50</math> years</b>							
0	525	28.2	1	1	1	1	1
1	398	21.4	<b>1.95 (1.09–3.51)</b>	<b>2.06 (1.09–3.90)</b>	1.32 (0.76–2.29)	1.98 (0.96–4.11)	1.29 (0.76–2.18)
2	349	18.7	<b>4.06 (2.32–7.12)</b>	<b>2.12 (1.12–4.02)</b>	<b>2.84 (1.69–4.77)</b>	<b>3.39 (1.69–6.78)</b>	<b>2.14 (1.30–3.54)</b>
3	295	15.8	<b>4.10 (2.28–7.37)</b>	<b>3.80 (2.02–7.16)</b>	<b>3.60 (2.11–6.12)</b>	<b>3.43 (1.70–6.91)</b>	<b>3.10 (1.86–5.16)</b>
$\geq 4$	296	15.9	<b>4.90 (2.72–8.82)</b>	<b>4.18 (2.19–7.98)</b>	<b>3.99 (2.30–6.91)</b>	<b>5.56 (2.77–11.19)</b>	<b>3.57 (2.11–6.04)</b>

Notes: Risk estimates are given as OR and 95% CI. Significant differences ( $P < 0.05$ ) are marked in bold. The results are stratified by age.

and 2.12 (95%CI 1.12–4.02) when exposed to two physical exposures. These associations increased in an exposure–response relationship where younger and older workers exposed to four or more physical exposures at work had ORs of 6.29 (95%CI 3.63–10.89) and 4.18 (95%CI 2.19–7.98) for reporting fatigued in the back after work, respectively. These are high odds which may have large consequences for workers with physical works. Furthermore, these results indicate that it may be more relevant to examine the summed number of physical exposures instead of single exposures separately. Examining the summed number of physical exposures provides insight into the accumulated physical strain during physical work, which better reflects the total amount of physical exposure at work. On the other hand, there may be a dose–response relationship between the duration of physical exposures during work and fatigue after work. Workers exposed to a single exposure for e.g. 75–100% of the workday may therefore potentially be as fatigued as the workers exposed to multiple physical exposures. Future studies should investigate the relation between time-wise variation in physical exposures and level of perceived fatigue. Additionally, workers with physical work often have work tasks, e.g. lifting tasks, where the back muscles are highly active during a prolonged period of time<sup>25</sup> which consequently increase the risk of muscular fatigue. In relation to this, studies have found pain in low back to be the most common musculoskeletal pain among workers with physical work.<sup>26–28</sup> Also, a structured evidence-based review found associations between pain and fatigue.<sup>29</sup> The study included 23 reports, or 22 studies, finding associations between pain and fatigue, and the review suggested fatigue to be related to the

occurrence of pain.<sup>29</sup> However, it may potentially be the other way around. Sustained muscle activity among workers have been found to cause muscular pain.<sup>30,31</sup> It therefore seems plausible that sustained muscle activity during work (both physical and sedentary work) leads to muscular fatigue which may lead to the development of pain. This may result in a vicious circle where fatigue leads to pain which again leads to fatigue, or the other way around. Hence, workplaces should be aware of the accumulated amount of physical exposure that the employees are exposed to, since fatigue can have enormous consequences for employees and workplaces.<sup>3–7,14,32,33</sup> Such recommendations can, however, not be suggested based on our cross-sectional data. Thus, longitudinal studies are needed to investigate associations between physical exposures and work-related fatigue for making general recommendations for workplaces.

This study contains both limitations and strengths. A limitation of the study is the cross-sectional study design, which does not allow for causal interpretations. Besides associations between physical exposure during work and bodily fatigue after work, it may as well be the other way around, where higher bodily fatigue results in over-reporting of physical exposure. For this reason, we dichotomized the exposure with the reference category being never or rarely/very little. Thus, any over-rating in the higher categories was collapsed into the same category and is thus unlikely to influence the results. However, this dichotomization also excludes the possibility to analyze the influence of exposure–response of percentage time of the workday on fatigue. Although the cross-sectional design has several limitations, a strength is that perceived level of physical fatigue after work

presumably relates closely in time to the physical exposures. For example, a hard day of work or several such days or weeks in a row may lead to fatigue, but subsequent recovery of days or weeks would probably not lead to a long-term association if the exposure were to be removed. Additionally, only ~53% replied to the questionnaire, which may have introduced a selection bias. However, a previous non-response analysis found a higher response rate among higher educated job groups, but a robustness analysis showed that the rating of the working environment was minimally influenced by this cause.<sup>34</sup> However, it cannot be ruled out that the study population represents a somewhat selected group. Since physical exposures during work were self-rated, the exposure measurement is less accurate and potentially more biased than if objective measurements had been used.<sup>35,36</sup> For example, a person's mood, health status, memory and interpretation of the questions could influence the replies and hence the results, e.g. by replying more negative if in a bad mood and/or having poor health,<sup>37</sup> which in this study could result in workers reporting more fatigued after work and a higher level of physical exposures during work. Future studies should use more objective and direct measurements to detect physical exposure and bodily fatigue, e.g. using 3D motion analysis, accelerometers and/or video to detect physical exposure, and electromyography to measure exposure and response variables, potentially supplemented with self-reports. Moreover, the results may be biased due to healthy worker effect, because older workers engaged in physically demanding work are leaving the labor market prematurely due to ill health. The results should therefore not be generalized to the society's older population, but to older workers engaged in physical work. This study also contains several strengths. A strength of the study is the large sample size for workers with physical works where we additionally stratified the workers by age (<50 and ≥50 years). The large sample size provides relatively high statistical power and thereby reduces the chances of statistical type II errors. Moreover, a cross-sectional study is relatively low cost compared to the huge amount of data generated. Since questionnaire-based data may be biased by the respondents mood, socioeconomic status, musculoskeletal disorders etc.,<sup>37,38</sup> the controlling for various confounders is a strength of this study. Another strength of the study is the analysis of the summed number of physical exposures during work, which to our knowledge is only used in one previous study.<sup>6</sup> This analysis provides a more comprehensive picture of the associations between physical exposures and bodily fatigue among workers with physical works, since physical work typically consists of more than one physical exposure during the workday.

In conclusion, physical exposures during physical work associate with increased fatigue after work in the body in general and in various body sections. Additionally, an exposure–response relationship was observed between an increased number of combined physical exposures and bodily fatigue among younger and older workers. These results underscore the importance of workplaces to be aware of physical work exposures and the associated fatigue to prevent potential injuries and sickness absence.

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## Key points

- Being fatigued after work may indicate an imbalance between work demands and capacity of the workers.
- The level of fatigue may vary across body sections, and workers may be affected differently across age-groups.

- This study reports associations between being exposed to various physical exposures during work and increased fatigue after work.
- Notably, this study observed an exposure–response relationship between number of physical exposures and bodily fatigue.
- Workplaces should consider the sum of physical work demands rather than focusing on single factors for ensuring sufficient recovery and preventing excessive fatigue from physical work.

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