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ORIGINAL ARTICLE

Associations of objectively measured forward bending at work with low-back pain intensity: a 2-year follow-up of construction and healthcare workers

Lars-Kristian Lunde, Markus Koch, Suzanne Lerato Merkus, Stein Knardahl, Morten Wærsted, Kaj Bo Veiersted

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Department of Work Psychology and Physiology, National Institute of Occupational Health, Oslo, Norway

Correspondence to
Dr Lars-Kristian Lunde, Department of Work Psychology and Physiology, National Institute of Occupational Health, Oslo 0363, Norway; Lars-Kristian.Lunde@stami.no

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ABSTRACT

Objectives This study aimed to determine possible associations between objectively measured forward bending at work (FBW) and low-back pain intensity (LBPi) among Norwegian construction and healthcare workers.

Methods One-hundred and twenty-five workers wore two accelerometers for 3–4 consecutive days, during work and leisure to establish duration of ≥30° and ≥60° forward bending. The participating workers reported LBPi (0–3) at the time of objective measurements and after 6, 12, 18 and 24 months. We investigated associations using linear mixed models with significance level p≤0.05 and presented results per 100 min.

Results The duration of ≥30° and ≥60° FBW was not associated with average LBPi during follow-up, neither for the total sample nor stratified on work sector. Furthermore, analyses on all workers and on construction workers only found no significant association between ≥30° or ≥60° FBW and change in LBPi over the 2-year follow-up. For healthcare workers we found a consistent significant association between the duration of ≥30° FBW at baseline and the change in LBPi during follow-up, but this was not found for ≥60° FBW.

Conclusions This study suggests that objectively measured duration of FBW in minutes is not associated with average levels of, or change in LBPi in construction workers over a 2-year period. In healthcare workers, exposure to ≥30° FBW was associated with change in LBPi, while we did not find this for ≥60° FBW. Results may indicate that the associations between FWB and LBP vary depending on type of work tasks, gender or sector-specific factors.

Key messages

What is already known about this subject?

- There is a high prevalence of musculoskeletal disorders in the construction and healthcare sectors.
- Long duration of forward bending of the upper body during work is suggested as a risk factor for developing low-back pain in physically demanding occupations.
- However, previous studies have largely relied on self-reported exposure duration, which provide inadequate evidence due to low methodological quality.
- The only published study using a prospective design and objective measures has investigated a mixed group of blue-collar workers and concluded there was no association.

What are the new findings?

- We investigated associations between objectively measured forward bending for 3–4 consecutive days and low-back pain in construction and healthcare workers, with a 2-year prospective design.
- Forward bending at work ≥30° was associated with a change in low-back pain intensity in healthcare, but not in construction; no associations were found for average pain.
- Results indicate that the associations between forward bending at work and low-back pain may vary depending on type of work tasks, gender or sector-specific factors, and that groups consisting of mixed blue-collar professions may hide possible associations in subgroups.

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INTRODUCTION

Low-back pain (LBP) is globally one of the largest contributors to years lived with disability[1] and therefore a major public health problem.[2] The high prevalence of musculoskeletal disorders in construction and healthcare sectors[3] highlights the importance of identifying work-related risk factors.

Laboratory studies suggest that load on the lumbar spine and muscle activity in the lower back increase in proportion to the degree of flexion of the upper body.[4 5] Further, that regular biomechanical loading of the lower back from forward bending may lead to tissue damage of spine and back muscles, resulting in increased LBP.[6 7] However, reviews on the association between forward bending at work (FBW) and LBP show conflicting results and highlight the methodological limitations pertaining to lack of objective measures.[8–13] The discrepant findings may be a result of recall bias connected to self-reported exposure duration, differences in question

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Key messages

How might this impact on policy or clinical practice in the foreseeable future?

- There is a potential difference between sectors in the relationship between forward bending and low-back pain, and this should be accounted for in future research and when aiming to reduce low-back pain as a result of mechanical exposures in physically demanding work.
- Therefore, preventive approaches by policy makers, practitioners, and workplaces may be different depending on professions/sector/gender.

interpretation or the effect of participants' pain levels attenuating the validity of self-reported exposure.[14–16] Thus, objective measurement methods are recommended in the investigation of physical exposures. Moreover, measurements over several days are preferable to single measurement days,[14 15] because they capture variations in exposure between workdays. However, few studies have measured FBW objectively for consecutive working days when investigating its association to LBP. To our knowledge, only two cross-sectional studies and one prospective study in Danish blue-collar workers are available, which all reported no association.[17–19] More studies with a prospective design and objective measures are needed to confirm these results.[17–19] We are not aware of any studies that provide this knowledge for the construction and healthcare sectors.

Generally, the development of LBP is of multifactorial origin with suggested individual risk factors being age and gender,[20] body mass index (BMI) and smoking.[21 22] Mechanical exposures at work, such as heavy lifting and overall heavy physical work, are also linked to LBP.[12] High seniority in professions with heavy work may further increase the risk of LBP due to accumulation of such exposures.[23 24] For the population presented in this study, we have previously found sitting at work to be associated with lower LBP levels in healthcare workers.[25] LBP is also associated with several psychosocial work factors including decision control, type of leadership and social climate at work.[20 26 27] When estimating the association between FBW and LBP one should strive to control for these aforementioned factors since they plausibly affect both exposure and outcome and therefore may act as confounders.

This study was designed as a part of a larger prospective cohort study,[28] and to answer one of the superior research questions we aimed to determine whether the objectively measured time spent FBW was associated with LBP intensity (LBPi) in construction and healthcare workers over a 2-year period.

We tested four hypotheses in two different designs:

1. Duration of ≥30° and ≥60° forward bending of the trunk at work is associated with the average LBPi during 2 years of follow-up.
2. Duration of ≥30° and ≥60° forward bending of the trunk at work is associated with change in LBPi between baseline and four collected time points in the 2 years of follow-up.

METHODS

Study population and design

Four construction companies and two local healthcare distributors in the Oslo area (total: n=1165; construction workers: n=580; healthcare workers: n=585) constituted the target population. Data sampling started in the first quarter of 2014 and ended in the first quarter of 2017. The purpose, format and methods of the study were presented to the workers at informational meetings located at their work site. Five hundred and ninety-four participants (construction workers: n=293; healthcare workers: n=301) agreed to participate. At baseline, all participants answered the study questionnaire. Of the participating sample, 178 construction workers and 193 healthcare workers additionally agreed to participate in technical measurements at baseline. The technical measurements consisted of sampling of body positioning by two accelerometers for 3–4 consecutive days while maintaining a short diary. All participants were followed up by questionnaires every 6 months for a total of 2 years. Exclusion criteria were: inadequate skills in reading and writing Norwegian, with the additional criteria of known allergic reaction to plaster, tape or bandages, or being pregnant in the group with technical measurements. Subjects diagnosed with severe or insufficiently treated cardiovascular disease or musculoskeletal disorders were not subjected to tests they could not perform. Sixty-six construction and 72 healthcare workers were selected for technical measurements to best fit logistics (availability, work schedules and profession). These subjects went through a standard clinical examination. All subjects signed a written informed consent form and the study was conducted in accordance with the Helsinki Declaration.

Instrumentation for technical measurements

We used ActiGraph GT3X+ sensors (ActiGraph, Pensacola, Florida, USA) to measure the acceleration, position and angle of body segments with a sampling frequency of 30 Hz. The accelerometers were placed on the participant's right thigh (medially between the iliac crest and the upper crest of the patella), and on the back, levelled with T1–T2.[28–30] The accelerometers are lightweight (19 g) and were fixed on the skin using double-sided tape (Fixomull, BSN Medical, Hamburg, Germany) and covered with transparent film (Tegaderm, 3M, St Paul, Minnesota, USA).

Forward bending during work

From raw data provided by the 3–4 days of accelerometer assessments at baseline, minutes spent in forward bent position were determined by a custom-made MATLAB-based program, Acti4 (National Research Center for the Working Environment, Denmark, and Federal Institute for Occupational Safety and Health, Germany). Studies have found the ActiGraph GT3X+ sensors' set-up to be valid for detecting durations of different upper body inclinations.[29–31] From the participants' diary, we categorised each day into periods of work, periods of leisure and periods of sleep. We excluded periods of sleep, periods during which the accelerometers were not worn and when data did not fulfil the measurement criteria (shorter than 4 hours or 75% of the mean length of all respective periods).[32] We present data on forward bending as the average daily duration in minutes with trunk flexion ≥30° and ≥60° from the individuals' neutral standing position. Flexion of ≥30° and ≥60° has previously been categorised as respectively mild and extreme flexions.[17 19]

Self-reported FBW

Participants reported the fraction of their daily work performed with forward bended trunk, with the response alternatives (0) *Never,* (1) *Very small part of the time,* (2) *Approximately 25% of the time,* (3) *Approximately 50% of the time,* (4) *Approximately 75% of the time,* and (5) *Almost all the time*.[33] This question was used as a proxy for change in exposure to FBW during the 2-year follow-up.

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Low-back pain intensity

Subjects were asked to rate their LBPi during the preceding 4 weeks. They rated LBPi on a 4-point scale (*not troubled*=0, *a little troubled*=1, *rather intensely troubled*=2 and *very intensely troubled*=3).[34] A manikin drawing facilitated localisation of different body regions.

Covariates

Individual factors

Information of age, gender, seniority in profession, BMI (kg/m^2) and smoking status was collected by self-reports. We classified participants as smokers if they smoked daily or occasionally.

Self-reported manual handling

Participants reported if they, during regular workdays, lifted something weighing more than 20 kg, with response alternatives (0) *No*, (1) *Yes, 1–4 times*, (2) *Yes, 5–19 times* and (3) *Yes, at least 20 times a day*.[33]

Psychosocial factors

We assessed decision control, fair and empowering leadership, and social climate in the organisation by items from the General Nordic Questionnaire for Psychological and Social Factors at work.[35 36] A full description of these questions is available in online supplementary material text A.

Objectively measured sitting

Simultaneously as measuring forward bending, we measured sitting duration for 3–4 days using two ActiGraph GT3X+ sensors placed at the hip and the thigh, a set-up valid for detecting sitting activities.[29 30]

Statistical analyses

To test the associations between FBW and LBPi, we used linear mixed models fitted by restricted maximum likelihood with a random intercept added for subject. We treated FBW duration in minutes as the main exposure variable and LBPi as the dependent variable. To test the preset hypotheses, we implemented analyses with two different designs: (1) the association between exposure to FBW in minutes and the average LBPi over the 2-year follow-up (ie, including FBW duration as main effect in the model); and (2) the association between exposure to FBW in minutes and the change in LBPi (ΔLBPi) between baseline and the four time points during the 2-year follow-up (ie, including FBW duration as main effect, time as categorical variable and an interaction between FWB duration*time). In order to remove a reversed causal effect between pain and exposure at baseline, which could affect results in analyses on average pain over 2 years, we removed baseline pain observations from the analyses investigating FBW and average LBPi. For design 1, the time effect of the exposure on the outcome was assumed to be equal for all time points, while in the second design time was treated as a categorical variable to provide estimates for every follow-up. Both designs were carried out on durations of ≥30° and ≥60° FBW. Due to previous knowledge on differences in gender distribution and work characteristics between the sectors, we performed analyses on the total sample and stratified by work sector. Both designs were built up as four models: model 1 as crude association between objectively measured FBW (≥30° or ≥60°) and LBPi (average or change); model 2 as model 1+adjustments for age, gender, smoking and BMI; model 3 as model 2+adjustments for heavy lifting; model 4 as model 3+adjustments for social climate, decision control, fair leadership and empowering leadership; and model 5 as model 4+adjustment for objectively measured sitting. We selected the variables prior to analyses. Variables with possible collinearity were examined for this, and we excluded seniority from the analyses due to its high correlation with age. Based on variation in absolute duration of workday, we additionally performed analyses with duration of FBW as percentage of work period. To detect potential differences between responders and non-responders, and the technical measurements group and the group only answering questionnaires, we compared group variables by independent sample t-test and Wilcoxon rank-sum test. Finally, as an indicator of change in job characteristics, we tested possible changes in self-reported FBW and social climate between baseline, 6, 12, 18 and 24 months with Friedman's analysis of variance.

We conducted statistical analyses in STATA V.13.0 (StataCorp, College Station, TX, USA) and associations were calculated by β–coefficients per 100 min with 95% CIs.

RESULTS

Twelve of the 138 selected employees were unable to participate due to various practical reasons (no show, acute illness, change in work location). One person was removed from analysis after reporting having Bechterew's disease. This led to a final study sample of 125 employees (construction n=61; healthcare n=64). See table 1 for subject characteristics, and figure 1 for distributions of LBPi for the full study period. There was no difference in self-reported forward bending at baseline between those undergoing technical measures and the group only answering questionnaires (p=0.164). Additionally, we found no differences in self-reported FBW (construction p=0.273; healthcare p=0.442) and reported social climate (construction p=0.304; healthcare p=0.318) between baseline, 6, 12, 18 and 24 months.

Total measurement time and missing data

We measured a total of 946 hours of work with an average of 7.6 work hours per day. From the 125 individuals in the study sample, accelerometer data were available for 95% (n=119) of the participants. Two per cent of the subjects did not answer the LBPi question at baseline. Twenty-two %, 42%, 42% and 47% missed the LBPi question or did not respond to the questionnaire at 6, 12, 18 and 24 months. Fifty-four subjects responded to all questionnaires, while 71 failed to respond on one or more follow-ups. Analyses on the construction workers showed no statistically significant differences between responders and non-responders concerning age, gender, objectively measured FBW and baseline LBPi. For healthcare, the non-responders were statistically significantly younger, had shorter duration of objectively measured forward bending and consisted of more males.

FBW and average LBPi

For all workers, analyses on the duration of ≥30° and ≥60° forward bending in minutes at work showed no significant associations with the average reported LBPi from the 2 years of follow-up (table 2). Similarly, we found no associations in the analyses stratified on construction or healthcare workers.

FBW and change in LBPi

Forward bending at ≥30°

Analyses of all workers and construction workers only showed no statistically significant associations between duration of ≥30° FBW and change in LBPi during follow-up (table 3). For healthcare workers, the analyses showed a trend of statistically

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Table 1 Descriptive characteristics of the study participants at baseline (n=125)

	Total (n=125)			Construction (n=61)			Healthcare (n=64)		
Variables	**%**	**Mean**	**SD**	**%**	**Mean**	**SD**	**%**	**Mean**	**SD**
Age (years)		42.0	11.9		39.8	13.5		44.1	9.9
Gender (male)	59.2			98.4			21.9		
Body mass index (kg/m^2)		25.3	3.6		25.6	3.3		25.0	3.8
Smokers	28.8			31.1			26.6		
Seniority in profession		16.4	11.2		16.9	12.6		16.0	9.7
Normal work hours per week		36.7	4.2		37.8	4.0		35.7	4.2
Work hours measured per day		7.6	1.5		8.2	1.8		7.1	0.8
Bending ≥30° at work (min)		86.4	46.2		94.3	52.8		79.2	38.2
Bending ≥60° at work (min)		21.5	19.7		27.7	25.0		15.8	10.3
LBPi at baseline (0–3)									
Not troubled	44.3			48.3			40.3		
A little troubled	25.4			26.7			24.2		
Rather intensely troubled	28.7			25.0			32.3		
Very intensely troubled	1.6			0.0			3.2		
Sitting duration at work (min)		165.0	104.3		158.2	114.6		171.6	93.8
Heavy lifting at work (0–3)*		0.9	1.1		1.5	1.3		0.4	0.6
Social climate at work (1–5)†		4.0	0.7		4.0	0.7		4.0	0.7
Decision control at work (1–5)‡		3.1	0.7		3.1	0.6		3.0	0.8
Fair leadership (1–5)‡		4.0	0.8		4.0	0.7		4.0	0.9
Empowering leadership (1–5)‡		3.5	1.0		3.1	0.9		3.8	1.0

*Response alternatives: (0) No, (1) Yes, 1–4 times, (2) Yes, 5–19 times, (3) Yes, at least 20 times a day.
†Response alternatives for supportive, trustful and comfortable climate: (1) Very little or not at all, (2) Rather little, (3) Somewhat, (4) Rather much, (5) Very much.
‡Response alternatives: (1) Very seldom or never, (2) Rather seldom, (3) Sometimes, (4) Rather often, (5) Very often or always.
LBPi, low-back pain intensity.

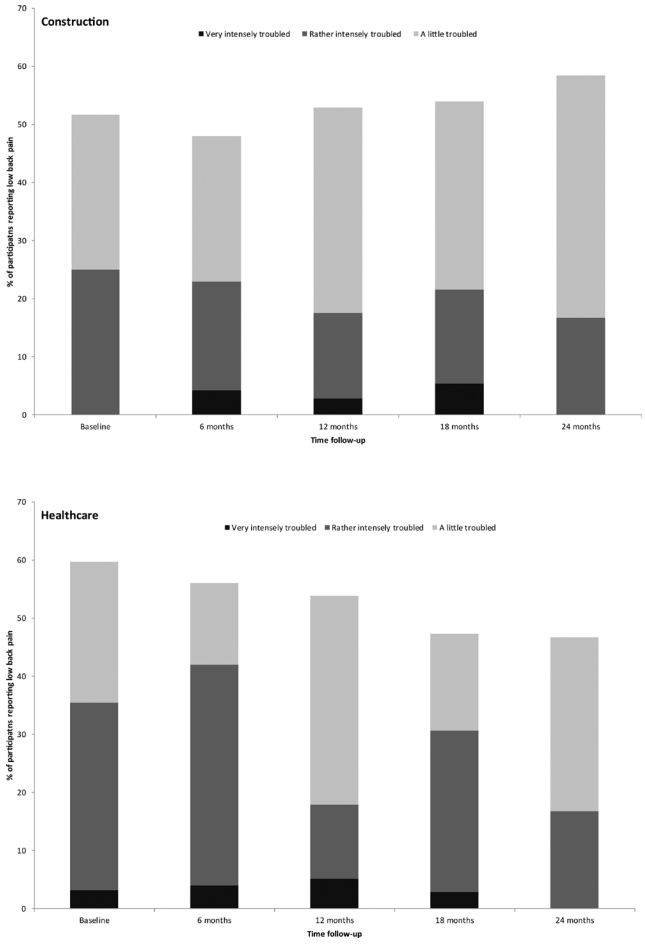

Figure 1 Low-back pain in construction and healthcare.

significant associations between forward bending and positive change in LBPi for all models at follow-up times T2, T3 and T4, but not T5 (table 3).

Forward bending at ≥60°

For all workers, and for construction workers only, analyses on ≥60° forward bending in minutes at work showed no statistically significant associations with the change in LBPi between baseline and any of the time points during follow-up (table 4). Analyses of healthcare workers showed statistically significant positive associations only at T3 for models 3 and 4 (table 4).

Additional analyses

Additional analyses on duration of ≥30° and ≥60° FBW as percentage of the work period consistently supported the results based on duration in minutes, both for average pain and change in pain. Analyses of ≥30° FBW as percentage on average pain in construction workers showed a statistically significant negative association (online supplementary tables A–C).

DISCUSSION

We did not find any association between duration of ≥30° or ≥60° FBW and the average level of LBPi during the 2-year follow-up in construction or healthcare workers. Similarly, no significant associations were found between ≥30° or ≥60° FBW and change in pain when analysing all workers or construction workers only. For healthcare workers there was a consistent significant association between the duration of ≥30° FBW and the change in LBPi between baseline and follow-up, but not for ≥60° FBW, where only T3 in adjusted models reflected significant results.

There are very few studies investigating the association between objectively measured FBW and LBP. A cross-sectional

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Table 2 Linear mixed model with exposure to ≥30° and ≥60° forward bending at work (per 100 min) and average low-back pain during follow-up (design 1)

	Model 1			Model 2			Model 3			Model 4			Model 5		
	Observations=291/141/150			Observations=285/140/145			Observations=284/139/145			Observations=281/138/143			Observations=281/138/143		
	Coefficient	95% CI	P value	Coefficient	95% CI	P value	Coefficient	95% CI	P value	Coefficient	95% CI	P value	Coefficient	95% CI	P value
≥30°															
All workers	−0.08	−0.50 to 0.24	0.625	−0.13	−0.47 to 0.21	0.453	−0.13	−0.46 to 0.21	0.467	−0.12	−0.45 to 0.21	0.480	−0.11	−0.44 to 0.21	0.486
Construction	−0.25	−0.64 to 0.14	0.204	−0.32	−0.72 to 0.08	0.113	−0.32	−0.72 to 0.08	0.121	−0.33	−0.71 to 0.05	0.089	−0.32	−0.71 to 0.06	0.100
Healthcare	0.26	−0.33 to 0.84	0.385	0.24	−0.38 to 0.86	0.448	0.24	−0.37 to 0.86	0.439	0.29	−0.35 to 0.92	0.377	0.15	−0.45 to 0.76	0.623
≥60°															
All workers	0.18	−0.56 to 0.92	0.638	0.13	−0.67 to 0.92	0.753	0.18	−0.63 to 0.99	0.667	0.20	−0.60 to 1.00	0.626	−0.26	−1.11 to 0.59	0.547
Construction	0.05	−0.76 to 0.85	0.912	−0.15	−1.01 to 0.71	0.736	−0.07	−0.95 to 0.81	0.873	−0.37	−1.25 to 0.51	0.409	−0.57	−1.51 to 0.38	0.243
Healthcare	1.70	−0.61 to 4.00	0.149	1.75	−0.72 to 4.21	0.164	1.72	−0.71 to 4.15	0.164	1.80	−0.66 to 4.27	0.151	0.02	−2.86 to 2.90	0.990

Observations: total observations included in linear mixed models for all workers/construction/healthcare.
Dependent variable: the average pain intensity from 6 to 24 months' follow-up (T2, T3, T4, T5).
Independent variables: Model 1: forward bending at work (min/workday). Model 2: as model 1+age, gender, smoking, body mass index (BMI). Model 3: as model 2+heavy lifting. Model 4: as model 3+social climate, decision control, fair leadership, empowering leadership. Model 5: as model 4+objectively measured sitting at work (min/workday).
.LBPi, low-back pain intensity.

Table 3 Linear mixed model with exposure to forward bending ≥30° at work (per 100 min) and change in low-back pain during follow-up (design 2)

		Model 1			Model 2			Model 3			Model 4			Model 5		
		Observations=407/197/210			Observations=399/196/203			Observations=398/195/203			Observations=393/194/199			Observations=393/194/199		
		Coefficient	95% CI	P value	Coefficient	95% CI	P value	Coefficient	95% CI	P value	Coefficient	95% CI	P value	Coefficient	95% CI	P value
Total	T2	0.12	−0.26 to 0.50	0.528	0.13	−0.25 to 0.51	0.502	0.12	−0.26 to 0.50	0.523	0.15	−0.23 to 0.52	0.451	0.14	−0.23 to 0.52	0.459
	T3	0.05	−0.34 to 0.45	0.799	0.05	−0.34 to 0.45	0.802	0.04	−0.35 to 0.44	0.833	0.06	−0.33 to 0.45	0.762	0.05	−0.34 to 0.44	0.785
	T4	0.25	−0.14 to 0.63	0.214	0.23	−0.16 to 0.62	0.255	0.21	−0.18 to 0.60	0.282	0.23	−0.16 to 0.62	0.242	0.22	−0.16 to 0.61	0.256
	T5	0.19	−0.28 to 0.66	0.422	0.22	−0.25 to 0.69	0.367	0.22	−0.25 to 0.69	0.364	0.24	−0.23 to 0.71	0.312	0.22	−0.25 to 0.68	0.362
Construction	T2	−0.23	−0.70 to 0.24	0.342	−0.25	−0.70 to 0.21	0.294	−0.26	−0.71 to 0.19	0.251	−0.25	−0.70 to 0.20	0.280	−0.25	−0.70 to 0.20	0.277
	T3	−0.33	−0.82 to 0.15	0.180	−0.36	−0.83 to 0.11	0.137	−0.38	−0.84 to 0.09	0.114	−0.36	−0.82 to 0.11	0.137	−0.35	−0.82 to 0.11	0.137
	T4	−0.05	−0.52 to 0.42	0.828	−0.15	−0.61 to 0.31	0.527	−0.19	−0.65 to 0.26	0.405	−0.18	−0.64 to 0.28	0.444	−0.18	−0.64 to 0.28	0.439
	T5	0.23	−0.40 to 0.85	0.478	0.24	−0.37 to 0.85	0.435	0.27	−0.33 to 0.86	0.384	0.28	−0.33 to 0.88	0.370	0.27	−0.33 to 0.87	0.375
Healthcare	T2	0.84	0.20 to 1.48	**0.010**	0.89	0.23 to 1.54	**0.008**	0.90	0.25 to 1.55	**0.007**	0.96	0.32 to 1.61	**0.003**	0.95	0.31 to 1.59	**0.004**
	T3	0.81	0.14 to 1.49	**0.018**	0.83	0.15 to 1.52	**0.018**	0.85	0.16 to 1.54	**0.016**	0.90	0.23 to 1.58	**0.009**	0.86	0.19 to 1.54	**0.012**
	T4	0.85	0.17 to 1.52	**0.014**	0.93	0.23 to 1.63	**0.009**	0.94	0.24 to 1.63	**0.009**	0.97	0.29 to 1.65	**0.005**	0.95	0.27 to 1.63	**0.006**
	T5	0.42	−0.29 to 1.12	0.251	0.46	−0.26 to 1.18	0.213	0.46	−0.27 to 1.18	0.217	0.48	−0.23 to 1.12	0.184	0.44	−0.27 to 1.15	0.226

T2: 6 months, T3: 12 months, T4: 18 months, T5: 24 months. Observations: total observations included in models for total/construction/healthcare; p≤0.05 in bold.
Dependent variable: change in pain between T1 and TX.
Independent variables: Model 1: forward bending at work (min/workday). Model 2: as model 1+age, gender, smoking, body mass index (BMI). Model 3: as model 2+heavy lifting. Model 4: as model 3+social climate, decision control, fair leadership, empowering leadership. Model 5: as model 4+objectively measured sitting at work (min/workday).

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Table 4 Linear mixed model with exposure to forward bending ≥60° at work (per 100 min) and change in low-back pain during follow-up (design 2)

		Model 1			Model 2			Model 3			Model 4			Model 5		
		Observations=407/197/210			Observations=399/196/203			Observations=398/195/203			Observations=393/194/199			Observations=393/194/199		
		Coefficient	95% CI	P value	Coefficient	95% CI	P value	Coefficient	95% CI	P value	Coefficient	95% CI	P value	Coefficient	95% CI	P value
Total	T2	−0.33	−1.24 to 0.58	0.475	−0.29	−1.20 to 0.61	0.528	−0.31	−1.22 to 0.59	0.497	−0.27	−1.18 to 0.63	0.552	−0.30	−1.21 to 0.60	0.510
	T3	−0.18	−1.07 to 0.71	0.697	−0.15	−1.04 to 0.74	0.735	−0.21	−1.11 to 0.69	0.644	−0.17	−1.07 to 0.72	0.708	−0.22	−1.12 to 0.67	0.625
	T4	0.29	−0.60 to 1.17	0.526	0.26	−0.62 to 1.15	0.560	0.19	−0.71 to 1.09	0.680	0.20	−0.70 to 1.09	0.668	0.14	−0.76 to 1.04	0.762
	T5	0.52	−0.47 to 1.51	0.301	0.59	−0.40 to 1.58	0.241	0.56	−0.43 to 1.55	0.266	0.60	−0.40 to 1.59	0.238	0.59	−0.41 to 1.58	0.246
Construction	T2	−0.62	−1.64 to 0.40	0.231	−0.64	−1.64 to 0.36	0.207	−0.70	−1.69 to 0.28	0.163	−0.74	−1.74 to 0.25	0.142	−0.75	−1.75 to 0.24	0.137
	T3	−0.62	−1.62 to 0.38	0.226	−0.67	−1.65 to 0.30	0.176	−0.81	−1.77 to 0.16	0.103	−0.78	−1.76 to 0.19	0.116	−0.79	−1.76 to 0.18	0.111
	T4	0.04	−0.96 to 1.03	0.941	−0.13	−1.11 to 0.84	0.789	−0.34	−1.32 to 0.64	0.498	−0.35	−1.34 to 0.63	0.483	−0.37	−1.34 to 0.62	0.460
	T5	0.28	−0.83 to 1.39	0.626	0.28	−0.81 to 1.36	0.619	0.20	−0.87 to 1.27	0.711	0.26	−0.82 to 1.34	0.635	0.26	−0.81 to 1.34	0.634
Healthcare	T2	1.64	−0.81 to 4.08	0.190	1.87	−0.62 to 4.36	0.141	1.96	−0.53 to 4.46	0.123	2.14	−0.41 to 4.70	0.100	1.97	−0.58 to 4.52	0.129
	T3	2.23	−0.29 to 4.89	0.081	2.66	−0.04 to 5.54	0.053	2.85	0.14 to 5.56	**0.039**	2.90	0.12 to 5.69	**0.041**	2.56	−0.23 to 5.35	0.072
	T4	1.22	−1.37 to 3.81	0.355	1.50	−1.19 to 4.18	0.275	1.58	−1.11 to 4.27	0.248	1.59	−1.14 to 3.33	0.253	1.34	−1.39 to 4.08	0.337
	T5	1.38	−1.47 to 4.23	0.342	1.50	−1.39 to 4.40	0.309	1.46	−1.43 to 4.36	0.322	1.51	−1.15 to 4.52	0.325	1.30	−1.70 to 4.31	0.395

T2: 6 months, T3: 12 months, T4: 18 months, T5: 24 months. Observations: total observations included in models for total/construction/healthcare: p≤0.05 in bold.
Dependent variable: change in pain between T1 and TX.
Independent variables: Model 1: forward bending at work (min/workday). Model 2: as model 1+age, gender, smoking, body mass index (BMI). Model 3: as model 2+heavy lifting. Model 4: as model 3+social climate, decision control, fair leadership, empowering leadership. Model 5: as model 4+objectively measured sitting at work (min/workday).

study on 198 Danish blue-collar workers reported no significant association of objectively measured duration of ≥30°, ≥60° and ≥90° FBW with LBP.[17] With a similar set of objective measures at baseline, Lagersted-Olsen *et al* collected LBP reports for 1 year prospectively in a group of mixed blue-collar professions and concluded there was no association between ≥60° FBW and the development or aggravation of LBP.[19] Our data from construction workers may be the most relatable to the study populations of mixed blue-collar workers in these two studies, and did support their findings of no association. We were not able to find studies with objective measures on workers in healthcare professions.

Lagersted-Olsen *et al* suggested three possible explanations for their findings of no association: (1) there is no association between forward bending and LBP; (2) there is an association, but limitations in design or methods preclude the detection of effect; and (3) the association is valid, but only when a third factor is present, under specific circumstances or in specific populations.[19]

Our study partly supported the third explanation: a significant association for healthcare workers, but not for construction workers. This may indicate that gender differences and/or differences in work characteristics influence pathogenic mechanisms differentially, leading to diverging results between the sectors. Therefore, large unspecific groups labelled as 'blue-collar' workers may hide possible associations in subgroups. For our study population in particular, differences in biomechanical exposure and attitude towards pain may explain some of the differences in findings between the sectors. Variation in work tasks over time could also influence associations in our study. We did not find any change in the mean self-reported duration of exposure to FBW for either group throughout the follow-up. However, self-reported exposures have weaknesses and other circumstances than merely the exposure itself that may influence how workers respond. Overall, it is likely that construction workers had more variation in physical work exposures throughout the 2 years of follow-up than the healthcare workers, mainly due to project building cycles. The healthcare workers are probably less exposed to large variations in work tasks, thus the 4-day recording of FBW may be a better representation of their regular job exposures over the years. Hence, baseline exposure may be a better predictor for future pain in healthcare workers than in the construction workers.

We consider the size of the coefficients of the association between ≥30° FBW and LBPi change in healthcare workers to be relatively large. Our results indicate a change in pain of around 0.8–0.9 units per 100 min spent in ≥30° FBW (table 3, healthcare T2–T4). In our sample, approximately 80 min per workday is on average spent in ≥30° forward bending positions, and around 28% of the healthcare workers have a daily exposure above 100 min (data not shown). Depending on pain scale and chronicity, 20%–30% improvement in a pain variable may be considered as a minimally clinically important change.[37 38] Thus, 100 min of ≥30° FBW would potentially qualify for a change in the pain response of that magnitude. The reduction in effect and non-significant result for the last follow-up (table 3, healthcare T5) may be due to a lower predictive value of baseline exposure on pain for this time point, 2 years after exposure measurement. As for ≥30° FBW, the coefficients for ≥60° FBW and change in LBPi in healthcare are consistently positive. Therefore, one could speculate that the results are relevant for more extreme angles of forward bending. However, we did not find a consistent result supporting this in our study, which is against a common biomechanical understanding. Still, all findings for

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≥60° generally show wide CIs, which reflects the low number of observations with extreme FBW, resulting in limited accuracy of the effect estimate.

An important aspect for future studies on this topic would be to consider the possibility that workers with pain avoid the posture under investigation, thereby causing an inverse relationship at a single point of measurement. The present findings of a non-significant protective relationship in construction workers for work duration in minutes were substantiated by a significant effect of ≥30° FBW duration as percentage of work period on average pain (online supplementary materials), and are also seen in studies of mixed blue-collar workers with objective measures of FBW.[17 19] We found a similar negative association of objectively measured upper arm inclination and shoulder pain in the same group of construction workers as in the present study.[39] Studies of 'naïve' pain-free workers starting a job and multiple exposure assessments would be crucial methods for untangling such dynamics in the relationship between FBW and LBP.

Strengths and limitations

A major strength of this study was the use of validated objectively measured FBW for several consecutive days, providing a precise measure of exposure and avoiding biases related to self-reported exposure assessment. Another strength was the 2-year follow-up of the pain outcome. The study was restricted to include only healthcare and construction workers, which attenuate confounding effects from large variations in work characteristics and socioeconomic factors. To our knowledge, no previous studies on construction and healthcare workers have provided the kind of information presented here.

We only measured duration spent in different angles of FBW, which is only one of several aspects of the work pattern. Thus, we did not consider posture variation, load, twisting or trunk rotation, which could show independent associations to LBP or provide additional information in FBW's relation to LBP. Objective measures increased resources used per participant as well as the extra burden put on participating individuals. This could lead to a possible selection of workers consenting to participate in the technical measurement group. However, we found no difference in age, seniority in profession, gender, LBPi at baseline or the mean self-reported FBW between the 125 participants with objective measures and the group only answering questionnaires. Something that indicates a certain level of representativeness. The sample size was relatively small, and we cannot outrule that a larger sample size could reflect findings for smaller effect sizes and provide more solid data for investigating ≥60° FBW.

Even though very few participants reported any serious spine-related injuries in the 12 months prior to baseline, we did not have information on long-term history of LBPi. Compared with a commonly used 0–10 measure, a pain scale of 0–3 will only detect large changes pain and could mask gender differences. Additionally, a more frequent collection of the pain assessments would capture fluctuations in pain better.[34] Multiple exposure assessments would also provide additional precision to prediction of pain during the follow-up and make it feasible to account for possible changes in exposure due to project cycles and season.

Concluding remarks

Objectively measured duration of FBW was not associated with average levels of, or change in LBPi over a 2-year period in construction workers. In healthcare workers, exposure to ≥30° FBW was associated with change in LBPi, while we did not find this for ≥60° FBW. Results may indicate that the associations between FWB and LBP vary depending on type of work tasks, gender or sector-specific factors.

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Contributors All authors contributed to form the study design. LKL and MK collected the data. LKL drafted the paper and was responsible for statistical analysis and interpreting the data. MK, SLM, SK, MW and KBV assisted with data interpretation and reviewed, edited and approved the final version of the manuscript.

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REFERENCES

1 Murray CJL, Vos T, Lozano R, *et al*. Disability-adjusted life years (DALYs) for 291 diseases and injuries in 21 regions, 1990–2010: a systematic analysis for the global burden of disease study 2010. *The Lancet* 2012;380:2197–223.
2 Hoy D, Bain C, Williams G, *et al*. A systematic review of the global prevalence of low back pain. *Arthritis Rheum* 2012;64:2028–37.
3 The Department of Occupational Health Surveillance, National Institute of Occupational Health, Norway. *Fact book on working environments 2018*. , 2018: 19 (3), 125–32.
4 Takahashi I, Kikuchi S-ichi, Sato K, *et al*. Mechanical load of the lumbar spine during forward bending motion of the trunk-a biomechanical study. *Spine* 2006;31:18–23.
5 Nachemson AL. Disc pressure measurements. *Spine* 1981;6:93–7.
6 Coenen P, Kingma I, Boot CRL, *et al*. Cumulative low back load at work as a risk factor of low back pain: a prospective cohort study. *J Occup Rehabil* 2013;23:11–18.
7 Kumar S. Cumulative load as a risk factor for back pain. *Spine* 1990;15:1311–6.
8 Burdorf A, Sorock G. Positive and negative evidence of risk factors for back disorders. *Scand J Work Environ Health* 1997;23:243–56.
9 Hoogendoorn WE, van Poppel MNM, Bongers PM, *et al*. Physical load during work and leisure time as risk factors for back pain. *Scand J Work Environ Health* 1999;25:387–403.
10 Wai EK, Roffey DM, Bishop P, *et al*. Causal assessment of occupational bending or twisting and low back pain: results of a systematic review. *Spine J* 2010;10:76–88.
11 Bakker EWP, Verhagen AP, van Trijffel E, *et al*. Spinal mechanical load as a risk factor for low back pain: a systematic review of prospective cohort studies. *Spine* 2009;34:E281–E93.
12 da Costa BR, Vieira ER. Risk factors for work-related musculoskeletal disorders: a systematic review of recent longitudinal studies. *Am J Ind Med* 2010;53:285–323.
13 Roffey DM, Wai EK, Bishop P, *et al*. Causal assessment of Awkward occupational postures and low back pain: results of a systematic review. *Spine J* 2010;10:89–99.
14 Koch M, Lunde L-K, Gjulem T, *et al*. Validity of questionnaire and representativeness of objective methods for measurements of mechanical exposures in construction and health care work. *PLoS One* 2016;11:e0162881.
15 Hansson GA, Balogh I, Byström JU, *et al*. Questionnaire versus direct technical measurements in assessing postures and movements of the head, upper back, arms and hands. *Scand J Work Environ Health* 2001;27:30–40.
16 Kwak L, Proper KI, Hagströmer M, *et al*. The repeatability and validity of questionnaires assessing occupational physical activity--a systematic review. *Scand J Work Environ Health* 2011;37:6–29.
17 Villumsen M, Samani A, Jørgensen MB, *et al*. Are forward bending of the trunk and low back pain associated among Danish blue-collar workers? A cross-sectional field study based on objective measures. *Ergonomics* 2015;58:246–58.
18 Villumsen M, Holtermann A, Samani A, *et al*. Social support modifies association between forward bending of the trunk and low-back pain: cross-sectional field study of blue-collar workers. *Scand J Work Environ Health* 2016;42:125–34.

Occup Environ Med: first published as 10.1136/oemed-2019-105861 on 14 August 2019. Downloaded from http://oem.bmj.com/ on August 21, 2019 at Statens Arbeidsmiljoinstitutt Biblioteket. Protected by copyright.

19 Lagersted-Olsen J, Thomsen BL, Holtermann A, *et al*. Does objectively measured daily duration of forward bending predict development and aggravation of low-back pain? A prospective study. *Scand J Work Environ Health* 2016;42:528–37.
20 Hoy D, Brooks P, Blyth F, *et al*. The epidemiology of low back pain. *Best Pract Res Clin Rheumatol* 2010;24:769–81.
21 Dario AB, Ferreira ML, Refshauge KM, *et al*. The relationship between obesity, low back pain, and lumbar disc degeneration when genetics and the environment are considered: a systematic review of twin studies. *Spine J* 2015;15:1106–17.
22 Ferreira PH, Beckenkamp P, Maher CG, *et al*. Nature or nurture in low back pain? results of a systematic review of studies based on twin samples. *Eur J Pain* 2013;17:957–71.
23 Sluiter JK. High-demand jobs: age-related diversity in work ability? *Appl Ergon* 2006;37:429–40.
24 Bern SH, Brauer C, Møller KL, *et al*. Baggage handler seniority and musculoskeletal symptoms: is heavy lifting in Awkward positions associated with the risk of pain? *BMJ Open* 2013;3:e004055.
25 Lunde L-K, Koch M, Knardahl S, *et al*. Associations of objectively measured sitting and standing with low-back pain intensity: a 6-month follow-up of construction and healthcare workers. *Scand J Work Environ Health* 2017;43:269–78.
26 Christensen JO, Knardahl S. Work and back pain: a prospective study of psychological, social and mechanical predictors of back pain severity. *Eur J Pain* 2012;16:921–33.
27 Eriksen W, Bruusgaard D, Knardahl S. Work factors as predictors of intense or disabling low back pain; a prospective study of nurses' aides. *Occup Environ Med* 2004;61:398–404.
28 Lunde L-K, Koch M, Knardahl S, *et al*. Musculoskeletal health and work ability in physically demanding occupations: study protocol for a prospective field study on construction and health care workers. *BMC Public Health* 2014;14:1075.
29 Stemland I, Ingebrigtsen J, Christiansen CS, *et al*. Validity of the Acti4 method for detection of physical activity types in free-living settings: comparison with video analysis. *Ergonomics* 2015;58:953–65.
30 Skotte J, Korshøj M, Kristiansen J, *et al*. Detection of physical activity types using triaxial accelerometers. *J Phys Act Health* 2014;11:76–84.
31 Korshøj M, Skotte JH, Christiansen CS, *et al*. Validity of the Acti4 software using ActiGraph GT3X+accelerometer for recording of arm and upper body inclination in simulated work tasks. *Ergonomics* 2014;57:247–53.
32 Gupta N, Christiansen CS, Hallman DM, *et al*. Is objectively measured sitting time associated with low back pain? A cross-sectional investigation in the NOMAD study. *PLoS One* 2015;10:e0121159.
33 Statistics, Norway. *Levekårsundersøkelsen 2009 (Survey of level ofliving 2009)*, 2009.
34 Steingrímsdóttir OA, Vøllestad NK, Røe C, *et al*. Variation in reporting of pain and other subjective health complaints in a working population and limitations of single sample measurements. *Pain* 2004;110:130–9.
35 Wännström I, Peterson U, Åsberg M, *et al*. Psychometric properties of scales in the General Nordic Questionnaire for Psychological and Social Factors at Work (QPSNordic): confirmatory factor analysis and prediction of certified long-term sickness absence. *Scand J Psychol* 2009;50:231–44.
36 Dallner M, Elo AL, Gamberale F, *et al*. *Validation of the General Nordic Questionnaire (QPS$_{Nordic}$) for psychological and social factors at work*. Copenhagen: Nordic Council of Ministers, Nord, 2000: 12. 171.
37 Mannion AF, Balagué F, Pellisé F, *et al*. Pain measurement in patients with low back pain. *Nat Clin Pract Rheumatol* 2007;3:610–8.
38 Farrar JT, Young JP, LaMoreaux L, *et al*. Clinical importance of changes in chronic pain intensity measured on an 11-point numerical pain rating scale. *Pain* 2001;94:149–58.
39 Koch M, Lunde L-K, Veiersted KB, *et al*. Association of objectively measured arm inclination with shoulder pain: a 6-month follow-up prospective study of construction and health care workers. *PLoS One* 2017;12:e0188372.

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