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Estimation of physical workload of the low-back based on exposure variation analysis during a full working day among male blue-collar workers. Cross-sectional workplace study

Markus Due Jakobsen[a,*], Emil Sundstrup[a], Mikkel Brandt[a,b], Roger Persson[c,d], Lars L. Andersen[a,b]

[a] National Research Centre for the Working Environment, Copenhagen, Denmark
[b] Sport Sciences, Department of Health Science and Technology, Aalborg University, Aalborg, Denmark
[c] Department of Psychology, Lund University, Lund, Sweden
[d] Department of Laboratory Medicine, Division of Occupational and Environmental Medicine, Lund University, Lund, Sweden

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ABSTRACT

This study aims to quantify physical workload of the low-back using exposure variation analysis (EVA) during a full working day among blue-collar workers with manual lifting tasks. One hundred and ten male employees (39 warehouse workers, 27 operators, 24 postal workers and 20 slaughterhouse workers) with manual lifting tasks from 12 workplaces participated. The workers performed standardized box lifts using 5, 10, 20 and 30 kg before and after a working day. Muscular activity of the low-back was measured throughout the working day using surface electromyography (sEMG). Corresponding sEMG-values for 0–30 kg lifts were identified using linear regression. EVA at exposure levels corresponding to "lifting periods" of [1-5, 5-10, 10-20, 20-30 and > 30] kg in time intervals [0–0.5, 0.5–1, 1-2, 2-5, 5-10, > 10] sec was computed. Back inclination was measured using triaxial accelerometers. Compared to the other job groups, the operators' low-back muscles were exposed to more short duration "lifting periods" with varying loads and more frequent medium duration high load "lifting periods", respectively. The operators also worked more with their back inclined (> 30°, > 60°, and > 90°) than the remaining job groups. Nonetheless, more than 41% of the workers performed heavy "lifting periods" that exceeded Danish lifting guidelines. This EVA demonstrates that almost half of the blue-collar workers were exposed to heavy low-back loading which puts them at risk of developing musculoskeletal disorders and low-back injury. Operators are, in particular, exposed to more short duration and medium duration "lifting periods" with varying load compared to warehouse-, postal- and slaughterhouse workers.

1. Introduction

The consequences of musculoskeletal disorders (MSD) and work-related injuries in terms of sickness absence, reduced work-ability and early retirement pose a huge burden on individuals, workplaces and societies across the world (Morken et al., 2003; Holmberg and Thelin, 2006; Bevan et al., 2009; Andersen et al., 2011). Quantifying exposure and the associated risk factors is a basic requisite for being able to develop preventive MSD strategies. Although several individual and psychosocial work factors have been identified as potential risk factors for MSD (Pincus et al., 2008), high physical work demands, like frequent and heavy lifting are generally consider the primary cause of MSD among blue-collar work (Pincus et al., 2008; da Costa and Vieira, 2009; Griffith et al., 2012; Sterud and Tynes, 2013; Andersen et al., 2016, 2017). However, the predominant use of self-report measures to quantify physical work demands may lead to misclassification of exposure. Indeed, translating data based on workers self-reports into recommendations for lifting limits is a difficult feat and typically associated with poor reliability and validity as a result of recall and response bias (Hansson et al., 2001; Stock et al., 2005; Barrero et al., 2009; Takala et al., 2010; Kwak et al., 2011). For this reason, and even if technical measurements are more expensive and time-consuming than self-reports, using the appropriate technical measurements to quantify exposure should, in theory, provide a more valid method for identifying physical risk factors (Prince et al., 2008; Innerd et al., 2015).

Technical measurements of physical exposure are commonly used to increase accuracy, precision and/or to validate self-reported measures (Burdorf and van der Beek, 1999; Barrero et al., 2009). However, when quantifying physical exposure with the intent to identify risk factors it

* Corresponding author. National Research Centre for the Working Environment, Lersø Parkalle 105, Copenhagen. Denmark.
E-mail address: mdj@nrcwe.dk (M.D. Jakobsen).

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Table 1
Characteristics of the job groups. Values are reported as Mean, SE and P (differences between the job groups).

	Warehouse workers			Operators			Postal workers			Slaughterhouse workers		
	Mean	SE	P	Mean	SE	P	Mean	SE	P	Mean	SE	P
N	39			27			24			20		
Height (cm)	179.3	1.1		178.5	1.5		177.7	1.3		180.3	1.5	
Weight (kg)	81.8	1.8	a	83.8	2.6	#	74.9	2.4	a#^	85.8	2.7	^
BMI	25.4	0.5	a	26.3	0.7	#	23.6	0.6	a#^	26.4	0.8	^
Low-back strength (Nm)	192.2	8.4	a	200.2	8.8	#	154.8	8.3	a#^	207.1	12.4	^

[a] Denotes difference between warehouse workers and postal workers. # difference between operators and postal workers. ^ difference between slaughterhouse workers and postal workers.

is essential to select the appropriate method and assessment procedure among a steadily increasing arsenal of methods and assessment procedures. One common method is to measure cardiovascular intensity using heart rate monitors. However, this method does not provide an estimate of the loading on specific parts of the body. Accordingly, movement sensors like accelero-, gonio- and inclinometers provide valuable information about the movement and inclination of the body segments (Villumsen et al., 2014). Then again one limitation is that movement sensors do not directly quantify the relative intensity of the task. Measuring muscular loading using surface electromyography (sEMG) and normalizing the activity to a reference contraction, on the other hand, is one of the most common ways to quantify the relative intensity and duration of work tasks like lifting (Attebrant et al., 1997; Anton et al., 2003; Jakobsen et al., 2014). A consequence of measuring sEMG during an entire working day is that the method generates considerable amounts of data that need to be reduced for interpretation. One data reduction method for sEMG and movement data analysis that has increased in interest for the last 25 years is the exposure variation analysis (EVA) (Mathiassen and Winkel, 1991). When used for sEMG analysis the EVA describes not only the intensity of muscular activity during a period of work, but also the duration at each intensity level. Accordingly, this method measures multiple exposure dimensions simultaneously which makes it ideal for quantifying exposures of varying load and duration such as occupational lifting.

Several tools and guidelines, such as the Danish Working Environment Authority (The Danish Working Environment Authority, 2008), the Revised NIOSH Lifting Equation, the Ohio BWC Lifting Tables (Ferguson et al., 2005) and the ACGIH TLV for Lifting (American Conference of Governmental Industrial Hygienists, 2009), have been developed to prevent work-related MSD and low-back injuries due to lifting. These guidelines primarily focus on the load, the perpendicular distance from the center of gravity, duration, frequency, and shape of the load. According to the Danish Working Environment Authority, the maximum weight limit for optimal conditions is 30 kg, for males and females, when the load is lifted at a 30 cm distance (length of underarm) to the center of gravity (The Danish Working Environment Authority, 2008). In comparison, the maximum weight limit is 23 kg when using the Revised NIOSH Lifting Equation (Waters et al., 1993). The Danish guidelines further states that non-optimal lifting conditions are when the load is too large, difficult to grasp, unstable, involves raised arms, bending or twisting of the trunk, a high frequency or occurs in a confined space (The Danish Working Environment Authority, 2008). Overall, these guidelines are very convenient when inspecting workplaces and tasks for excessive lifting that may place the worker at risk of MSD and low-back injuries. The Danish Work environment Authority generally performs a visual inspection of a few random samples within each job group and thereby determines whether these job groups need increased regulation. However, as this inspection is observer dependent and based on a few momentary samples per job group the chances of over- or under-regulating are vast. Quantifying exposure, i.e. the amount of heavy and frequent lifting, on larger populations and during the entire working day will, therefore, provide more insight on the average amount of excessive exposure within each job group. However, as long as all the guidelines are based on the absolute weight of the load and not relative to the individual capacity, sEMG normalization procedures like percent of maximum voluntary contraction sEMG are not suitable as a reference. Hence, normalizing the sEMG signal to a reference in absolute kgs that corresponds to the limit of excessive lifting may be a more optimal approach.

Previous literature has shown that work demands of blue-collar workers like slaughterhouse-warehouse-, postal workers, and operators involve high loading, yet with different frequencies of exposure, which may imply an increased risk of MSD in the low-back and upper extremities (Viikari-Juntura, 1983; Jørgensen et al., 1989; Jensen et al., 1993; Marras et al., 1999; Anton et al., 2003; van Rijn et al., 2009). Documentation on whether these loadings actually exceed the lifting guidelines is scarce, but could i.e. be investigated by EVA of the muscular loading during a working day. The aim of this study, therefore, was to quantify low-back muscular load, back inclination and exposure to risk factors for MSD and low-back injury using exposure variation analysis during a full working day among job groups with manual lifting tasks.

2. Methods

2.1. Study design

A cross-sectional workplace study was conducted in 2011 at twelve different blue-collar companies across Denmark. Muscular load was measured throughout an entire working day among employees exposed to a high number of lifting tasks.

2.2. Participants

One hundred and ten male employees (39 warehouse workers, 27 operators, 24 postal workers and 20 slaughterhouse workers) with manual lifting tasks from twelve blue-collar workplaces participated (Table 1). Participant recruitment was performed in cooperation with the Confederation of Danish Industry, Confederation of Danish Employers, Danish Construction and the Danish Chamber of Commerce. Only companies where the employees performed manual lifting, however not patient transfer, were included in the study. Exclusion criteria were hypertension above 160/100 mmHg, disc prolapse or other serious chronic diseases. Two companies out of the initial 14 recruited companies and in total 90 workers who were not operators, warehouse-, postal- and slaughterhouse workers were excluded from the analysis (see flowchart in Fig. 1).

The participants were informed about the purpose and content of the study and gave written informed consent for participation. The study was approved by the Local Ethical Committee (H-3-2010-062) and conformed to The Declaration of Helsinki.

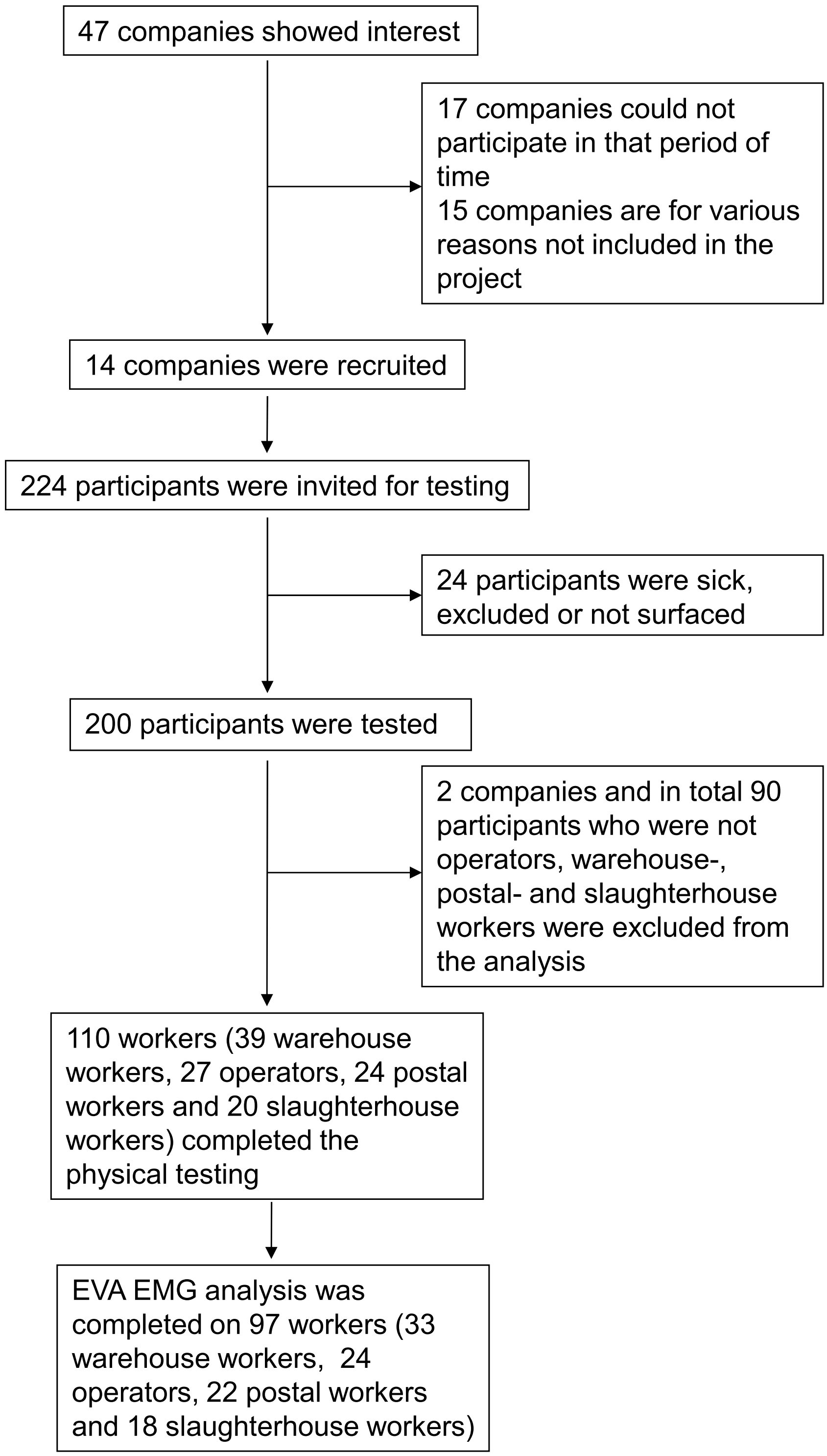

Fig. 1. Flowchart of number of companies and participants included in the study and analysis.

2.3. Description of the job types

The following descriptions are based on observations and interviews with selected workers and managers of the respective job types.

2.3.1. Warehouse workers

The typical work tasks of the included warehouse workers were to prepare and complete orders for delivery or pickup. These tasks included manual exerting labor such as loading/unloading of shelves or vehicles, packing, wrapping, labeling and shipping large packages. Less exerting tasks were creating inventory lists and maintaining a clean environment.

2.3.2. Operators

The operators work tasks included setting up machines to start a production cycle, controlling, maintaining and adjusting machine settings and feeding material to the machines. The operator's job, therefore, was to make sure that the machines were working at full capacity, were stocked with needed materials, were well-maintained, and periodically checked. These tasks included exerting low-back exposures when adjusting and loading the machines i.e. in awkward body postures.

2.3.3. Postal workers

The postal workers included both delivery- and package section workers. The delivery workers distributed mail and packages by either bicycle or car in the Copenhagen area. The package section workers sorted and handled packages for delivery. Both delivery and package work may include exerting lifting tasks.

2.3.4. Slaughterhouse workers

The slaughterhouse workers' job tasks included cutting, trimming, skinning, washing and sorting pigs into edible portions and packaging the cold cut meats. The work tasks, therefore, contain a high number of repetitions especially exerting the arm, shoulder, and hand and to some extent the low-back.

2.4. Experimental procedure

The participants were informed to show up at the worksite for physical testing two times during the day of testing; 40 min before work and immediately after work. A lifting task was performed on both occasions and a more strenuous physical test of maximum voluntary contraction (MVC) was performed at the end of the workday. This sequencing of testing was selected to avoid inducing fatigue in the morning which would influence the subsequent EMG-measurements obtained during the working day.

2.4.1. Lifting task

The lifting task was performed by manually lifting a box with a load of 5, 10, 20 or 30 kg and with a 2 min rest period in between. The load was placed and fixated in a box of 0.54 × 0.34 × 0.20 m (width, depth, and height, respectively) and was lifted from the floor and placed on the table (height 0.75 m) one time per load. The instructor lifted the load down from the table and placed it on the floor. The load was increased from 5 to 30 kg. However, if the participant was un-secure whether he safely could lift 30 kg, he was instructed not to lift the weight.

2.4.2. Maximal voluntary isometric contraction (MVC)

Maximal muscle strength of the back extensor muscles was performed as isometric MVC at the end of the workday (Jakobsen et al., 2012a). The low-back extensor MVC was measured in a standing position with a strain gauge dynamometer connected horizontally with a strap around the shoulders at the level of insertion of the deltoid muscle on the upper arms. To fixate the hip while maximally extending the back from a slightly flexed position (~5° back inclination), the subject was placed facing the dynamometer with the pelvis against a plate positioned so the upper edge was aligned with the subject's iliac. The subject was instructed and verbally encouraged to ramp up the muscle force while reaching peak force after approximately 3 s.

2.5. Assessment of muscular workload

2.5.1. Surface electromyography (sEMG) recording and filtering

sEMG activity was recorded from the low-back (erector spinae). The electrodes were placed on the left or right side determined by their dominant hand. A bipolar surface sEMG configuration (White Sensor, Ambu A/S, Ballerup, Denmark) and an inter-electrode distance of 2 cm were used (Andersen et al., 2006, 2008b, a, Jakobsen et al., 2011; 2012b). To effectively lower the impedance to less than 10 kΩ the skin of the respective area was prepared with scrubbing gel (Acqua gel, Meditec, Parma, Italy) before affixing the electrodes. The electrodes were subsequently connected through thin cables to a datalogger (Nexus10, Mind Media, Netherlands) that was placed in a flexible belt to ensure mobility for the worker throughout the working day. Placement of the electrodes followed SENIAM recommendations (www.seniam.org).

sEMG activity of each muscle was sampled at 1024 Hz and saved in separate data files using Nexus10 data loggers (Mind Media, Netherlands). The sEMG data was digitally filtered according to the linear envelope method (Winter 1990); a highpass filtering (10 Hz cutoff, 4th order Butterworth filter) followed by a full-wave rectification and lastly a lowpass filtering (sEMG: 2.2 Hz cutoff, 4th order Butterworth filter) using custom-made MatLab programs (Mathworks).

The sEMG-signals of the low-back were normalized and converted into kgs based on the corresponding linear regression sEMG-values for 5, 10, 20 and 30 kg obtained during the lifting task. Linear regression of the sEMG-values obtained during the lifting task, before and after the working day, was therefore used to adjust the EMG-measurements for any potential build-up of muscle fatigue throughout the day. Lifts consisting of exceptional high or low sEMG-values i.e. signal artefacts were excluded from the linear regression analysis using visual inspection of the data.

2.5.2. Exposure variation analysis (EVA)

The EVA consisted of normalized sEMG exposure levels corresponding to lifting a box/load of > 1- ≤5, > 5 - ≤10, > 10 - ≤20, > 20 - ≤30 and > 30 kg in time intervals of 0–0.5, > 0.5 - ≤1 (short duration), > 1 - ≤2, > 2 - ≤5 (medium duration), > 5 - ≤10, > 10 (long duration) seconds. The occurrence of these EVA exposure events will be identified as "lifting periods" even though we are unable to specify whether these exposures stem from actual lifting tasks. The EVA was computed in 30-min intervals and summed up throughout the working day and finally normalized for the duration of each workday so each working day was 7.5 h. Accordingly, 27 events at 10 kg in the 5-10 s interval, indicates the total number of times the participant was exposed to muscle activity corresponding to lifting a 10 kg load for a duration between 5 and 10 s during the 7.5 h working day.

2.6. Assessment of back inclination

One tri-axial accelerometer (ActiGraph GT3X, ActiGraph LLC, Pensacola, FL, USA) with a dynamic range of ± 6G and a 12-bit precision was used to detect back inclination. The accelerometer was placed at the processus spinosus at the level of T1-T2 to measure forward bending of the trunk (Faber et al., 2009; Korshøj et al., 2014). Data was acquired at 30 Hz and subsequently, low-pass filtered using a 5 Hz fourth-order Butterworth filter (Skotte et al., 2014).

The Acti4 software (The National Research Center for the Working Environment, Copenhagen, Denmark and Federal Institute for Occupational Safety and Health (BAuA), Berlin, Germany) was used to detect the back inclination (Korshøj et al., 2014). The inclination was adjusted for the individual reference measurements (i.e. 15 s of erect standing in neutral position 0°) obtained before and after the working day.

2.7. Statistical analysis

A general linear model, PROC GLM of SAS version 9.4. adjusted for age, BMI and back muscle strength was used to describe the differences in EVA and back inclination between the four job groups. Estimates are presented as least square means and 95% confidence intervals. In addition, a Chi-square test was used to test for differences in the frequency distribution (percentage of workers lifting i.e. at least 1 kg more or less than 120 times per hour) between job groups. P-values ≤0.05 were considered statistically significant.

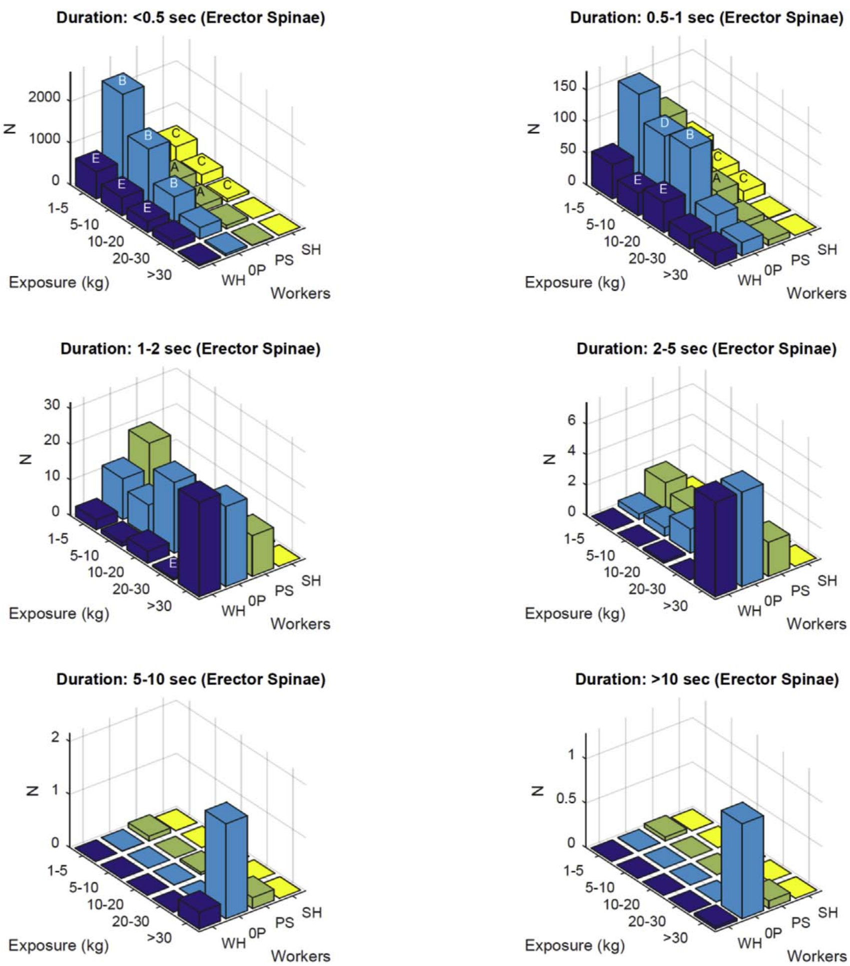

Fig. 2. Muscle loading of the erector spinae based on EVA among Warehouse workers (WH), Machine operators (MO), Postal workers (PS) and Slaughterhouse workers (SH). The values are presented as least square means of the number of events (N) the muscle has been exposed within this EVA-category (exposure level in kg at a duration level in sec.) and adjusted for back extensor strength. Letter A to E denotes significant post hoc differences between job groups for exposure levels with a main effect. A: operators > postal workers; B: operators > postal workers, slaughterhouse workers and warehouse workers; C: operators > slaughterhouse workers; D: operators > slaughterhouse workers and warehouse workers; E: operators > warehouse workers.

3. Results

3.1. Study population

On average, the postal workers had lower BMI and back extensor strength than the remaining job groups (Table 1). These differences were controlled for by including BMI and back extensor strength in the statistical analysis.

3.2. Muscular load (EVA)

The EVA showed that the operator's low-back muscles were exposed to more short duration lifts (> 0.5 s and 0.5–1 s) with loads varying from 1-20 kg and 5-20 kg, compared to the other job groups (Fig. 2). For the medium duration lifts (1-2 s) the operators were exposed to more frequent high low-back loadings (20-30 kg) compared to warehouse-, slaughterhouse, and postal workers.

There were no differences between the job groups in the number of lifts of more than 1 kg, 25 kg, and 30 kg, respectively. Further, the Chi-square test did not demonstrate differences in the percentage of the workers lifting at least 1 kg more than 25 times per hour, lifting at least 25 kg or at least 30 kg, respectively (Table 2).

3.3. Body inclination

Differences were also found for body inclination ($p < 0.05$). Compared to the other job groups, the operators performed more work with the back bent more than 30°, 60° and 90° from neutral erect position (0°) (Table 2).

4. Discussion

The present study demonstrated that almost half of the investigated blue-collar workers were exposed to heavy low-back loading that exceeds Danish lifting guideline recommendations. Altogether, our data show that EVA based on sEMG, normalized to absolute loadings, is a feasible method for quantifying muscular load and risk factors for MSD and low-back injury among job groups with frequent lifting tasks.

As the included job groups all performed lifting tasks as a part of their daily work routine the exposure assessed by the EVA was to a large degree similar across the job groups, however, differences did exist. We found a main effect for lifting periods of short duration with medium loadings and for medium duration with heavy loadings. Specifically, operators experienced higher exposure than warehouse-, postal- and slaughterhouse workers. Albeit not investigating the exact same study population, this is somewhat in contrast with the findings of Anton et al. who showed, using a cluster-based EVA of grip-finger muscle activity, that operators perform less high-intensity short-duration (0-3 s) contractions and more low-intensity contractions of prolonged duration (> 3 s) compared to mechanics (Anton et al., 2003). However, a part of an operator's job description is actually to maintain and repair the machines they are operating. Especially, these procedures, when bending into or under the machinery to perform adjustments, may impose heavy loadings in awkward positions. Noteworthy, the operators had prolonged durations of forward bending compared to the other job groups which may put them at an even higher risk of low-back injuries.

In our study, the postal workers had the lowest BMI and muscle strength when compared to the other job groups. Even though we

Table 2
Number of lifts (events with muscular loading corresponding to an exposure of > 1 kg, > 25 kg and > 30 kg for at least 0.5 s), percentage of workers lifting loads (> 1 kg > 25 times per day; > 25 kg; > 30 kg) and hours with bended back (> 30°, > 90°, > 90°). Values are reported as mean (95% confidence interval).

	Warehouse workers		Operators		Postal workers		Slaughterhouse workers	
	Mean	95 CI	Mean	95 CI	Mean	95 CI	Mean	95 CI
Number of lifts > 1 kg (N)	741	(410 - 1072)	1365	(866 - 1864)	891	(500 - 1283)	761	(583 - 1234)
Number of lifts > 25 kg (N)	59	(-38 - 157)	53	(10 - 96)	8	(-1 - 18)	17	(2 - 11)
Number of lifts > 30 kg (N)	51	(-34 - 135)	41	(1 - 81)	7	(-2 - 15)	12	(1 - 8)
Percentage of workers lifting > 1 kg more than 25 times per day (%)	84.9		83.3		90.9		100.0	
Percentage of workers lifting > 25 kg (%)	40.6		73.9		54.6		61.1	
Percentage of workers lifting > 30 kg (%)	40.6		73.9		50.0		44.4	
Time with back bended > 30° (h)	0.81	(0.65–0.97)	1.52	(1.15–1.89)*	0.88	(0.68–1.08)	0.84	(0.53–1.19)
Time with back bended > 60° (h)	0.14	(0.1–0.18)	0.46	(0.28–0.64)*	0.26	(0.18–0.34)	0.05	(0.03–0.07)
Time with back bended > 90° (h)	0.01	(0.01–0.01)	0.12	(0.06–0.18)*	0.07	(0.03–0.11)	0.00	(0 - 0)

adjusted for these differences in the statistical analysis, the postal workers were also, to some extent, less exposed to heavy and frequent loadings than the operators. Thus, had the postal workers been exposed to the same absolute loading as the operators, they would most likely have increased their risk of MSB and low-back injuries even further.

According to the Danish lifting guidelines, a load of 30 kg is set as the maximal limit while lifting in an optimal erect position with the load no further than 30 cm from the body center of mass (The Danish Working Environment Authority, 2008). There were no differences between the job groups in the number of "lifting periods" with a duration larger than 0.5 s and above 30 kg. However, the EVA analysis indicates that more than 40% of all the included workers performed lifting that exceeded this limit. When using 25 kg as a conservative estimate of the Revised NIOSH Lifting Equation (Waters et al., 1993), which is set to 23 kg, the average percentage (58%) of workers exceeding this threshold was even higher. In a Meta-Analysis on the effect of lifting during work on low-back pain (LBP), Coenen et al. found that lifting loads of more than 25 kg or lifting at a frequency of at least 25 lifts per day will increase the annual incidence of LBP by 4.3% and 3.5%, respectively (Coenen et al., 2014). In the present study, more than 83% of the included workers were exposed to low-back loadings corresponding to lifting at least 1 kg more than 25 times per day. Because the average number of lifts was 933 lifts/per day (lifts defined as exposures of at least 1 kg for more than 0.5 s), one can conclude that the risk of developing LBP is particularly high among the studied blue-collar job groups. The Danish lifting guidelines further state that the worker is at risk of MSD if he or she performs frequent lifting (The Danish Working Environment Authority, 2008). With respect to this guideline, and that slaughterhouse work is known to involve a high work pace with repetitive lifting of meat parts (Viikari-Juntura, 1983; Frost et al., 1998), it is interesting to observe that the slaughterhouse workers in our study were not exposed to a higher frequency of "lifting periods" than the remaining job groups.

Altogether, this EVA represents a feasible method for objectively estimating not only intensity and duration during a workday, but also pinpoint the total amount of occurrences of excessive loading (i.e. that exceeds the recommended lifting guidelines and the accompanied risk factor thresholds for MSB and low-back injury). Hence, this method may offer a useful tool for the working environment authorities as it provides the opportunity to perform large-scale objective inspections during the entire working day instead of only a few random momentary samples per workplace.

4.1. Strength and limitations

A strength of the study is that the present EVA provides a unique method for identifying job groups at risk of excessive loading based on the absolute load in kg. The estimated load measured throughout the working day was based on linear regression of a sequence of box lifts with varying loads performed in a controlled pace before and after the workday. However, as muscle activity not only depends on the distance, the inclination of the back and the amount of external load applied to the muscle but also the velocity and acceleration of the movement and contraction speed (Jakobsen et al., 2013), the present load in kg may in some situations vary from the actual lifted load. Accordingly, quickly lifting a load of 10 kg with a large distance from the body or in an inclined position may evoke an equal amount of muscle activity and compression forces on the spine as lifting a 30 kg box in an upright position close to the body. Nevertheless, as we were unable to synchronize the measurement of muscle activity and accelerometry, we did not identify the shear forces applied to the joints within each lift. Future studies could use the present method in a prospective study to determine the exposure-response association between physical workload and risk of low-back pain and injury.

As we aimed at recruiting a representative sample of blue-collar workers with lifting tasks and a large variation in job tasks within each job group, the present data may only be generalized to the average worker within a job group and not to the specific workstations or tasks within a job group. In example, some postal workers delivered mail using a car, others using a bike and some also sorted and handled the mail and packages. Moreover, one of the two slaughterhouse factories slaughtered and butchered pigs whereas the other factory mainly produced cold cut meats. To identify the specific work tasks that increase the risk of injury and MSD the EVA needs to be accompanied by a detailed time-log of the tasks performed or i.e. simultaneous anonymized video recordings of the work tasks performed during the workday (Brandt et al., 2015).

5. Conclusion

The results from this study demonstrate that almost half of the blue-collar workers perform heavy lifting in a way that puts them at risk of getting a low-back injury or develop LBP. In addition, the results also indicate that EVA, normalized to absolute loadings, seems to be a feasible objective method for identifying the occurrence of these risk factors during the entire workday and thus drastically reduce the need for making visual inspections. Even though the included job groups all performed heavy and frequent lifting tasks, the operators were exposed to even more inclined and repetitive low-back loading compared with warehouse workers, postal workers, and slaughterhouse workers.

Conflicts of interest

The authors declare that they have no competing interests.

Authors' contributions

MDJ, RPE and LLA designed and led the study and MDJ, ES and MB collected the data. MDJ and LLA analyzed the data and all authors were involved in the data interpretation. MDJ drafted the manuscript and all co-authors revised it critically for important intellectual content. All authors have read and approved the final manuscript.

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