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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

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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 tri-axial 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

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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#ˆ	85.8	2.7	ˆ
BMI	25.4	0.5	a	26.3	0.7	#	23.6	0.6	a#ˆ	26.4	0.8	ˆ
Low-back strength (Nm)	192.2	8.4	a	200.2	8.8	#	154.8	8.3	a#ˆ	207.1	12.4	ˆ

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