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ABSTRACT

The aim was to classify lifting activities into low and high risk categories (according to The Danish Working Environment Authority guidelines) based on surface electromyography (sEMG) and trunk inclination (tri-axial accelerometer) measurements. Lifting tasks with different weights, horizontal distance and technique were performed. The lifting tasks were characterised by a feature vector composed of either the 90th, 95th or 99th percentile of sEMG activity level and trunk inclinations during the task. Linear Discriminant Analysis and a subject-specific threshold scheme were applied and lifting tasks were classified with an accuracy of 65.1–65.5%. When lifts were classified based on the subject-specific threshold scheme from low and upper back accelerometers, the accuracy reached 52.1–58.1% and 72.7–78.1%, respectively. In conclusion, the use of subject-specific thresholds from sEMG from upper trapezius and erector spinae as well as inclination of the upper trunk enabled us to identify low and high risk lifts with an acceptable accuracy.

Practitioner Summary: This study contributes to the development of a method enabling the automatic detection of high risk lifting tasks, i.e. exposure to high biomechanical loads, based on individual sEMG and kinematics from an entire working day. These methods may be more cost-effective and may complement observations commonly used by practitioners.

1. Introduction

High physical workload, e.g. heavy manual lifting, is associated with several risk factors for the worker. This increases the risk of long-term sickness absence (Andersen et al. 2016; Lund et al. 2006), early retirement (van den Berg, Elders, and Burdorf 2010; Lund, Iversen, and Poulsen 2001), and disability pension (Lahelma et al. 2012; Ropponen et al. 2014). Construction work is among the jobs most commonly associated with high physical load and the prevalence of musculoskeletal disorders (MSD), especially low back pain and neck/shoulder pain (Boschman et al. 2012). Furthermore, construction work is characterised by a high degree of heavy lifting and working positions with forward and side bending of the trunk (Boschman et al. 2011) which have shown to increase the risk of MSD (Mayer, Kraus, and Ochsmann 2012). As a result, a study by Alavinia, van Duivenbooden, and Burdorf (2007)

suggests that interventions should focus on reducing the physical workload for construction workers as a high physical load is related to a gradual loss of working ability (Alavinia, van Duivenbooden, and Burdorf 2007). Furthermore, the consequences of physical workload increase with age due to the age-related loss of physical capacity (Burr et al. 2017).

The physical load associated with lifts necessitating forward or sideways bending of the trunk has been widely investigated in order to define high risk lifts with respect to low back injury (Marras 2000). The lifting guidelines from The National Institute for Occupational Safety and Health (NIOSH) state that in order to avoid low back injury the biomechanical load of the L5/S1 joint should not exceed 3400 N (Waters, Putz-Anderson, and Garg 1993, 1994). Another example is given in the guidelines of The Danish Working Environment Authority (Arbejdstilsynet 2005), which state that the allowed lifting load is to be decreased when aggravating factors such as longer reaching distance

or lifting with a rotated back are present. However, these lifting guidelines are based on static measurements that may underestimate the dynamic load on the back (Chaffin and Page 1994). Furthermore, lifting guidelines are often partly based on subjective visual observation, which makes it difficult to identify whether a lift exceeds the worker's physical capacity. In spite of the available observational methods, lifts are issue to subjective bias and difficulty of observing several test subjects at the same time. Thus, it is difficult to obtain an accurate estimate of the physical load during working situations using only observations (Eliasson et al. 2017; Takala et al. 2010). Moreover, a study by Trask and co-workers showed that in most situations assessment of trunk and upper arm inclination was more cost-effective using inclinometers than using visual posture observations (Trask et al. 2014).

Numerous studies suggest the possibility of utilising surface electromyography (sEMG) to obtain an objective measure of the physical load during working days (Gagnon, Plamondon, and Larivière 2016; Jakobsen et al. 2014). Other studies suggest to utilise measures of the kinematics of the trunk (Balaguier et al. 2017; Lagersted-Olsen et al. 2016; Lunde et al. 2017; Robert-Lachaine et al. 2017; Villumsen et al. 2016) or a combination of these methods (Samani et al. 2012). So far, most studies based on *in situ* assessments have studied bending and torsion of the trunk but have not provided assessments of the physical loads (Balaguier et al. 2017; Villumsen et al. 2015, 2016). The current body of literature reinforces the need for direct objective measures enabling delineation of lifts with low or high risk of contracting low back injuries. Therefore, the aim of the present study was to assess the accuracy of sEMG and kinematic measurements to detect low or high risk lifts during standardised conditions. For that purpose, we used a Linear Discriminant Analysis (LDA) to reduce the dimensions of the data-set and classify the lifts as either low or high risk lifts according to the guidelines of The Danish Working Environment Authority.

2. Methods

2.1. Study design

Twenty-six healthy male office workers participated in the study, which was conducted in Copenhagen,

Table 1. Anthropometric data for the study population presented as mean ± SD. Please note that one subject was extracted from the analysis because of technical issues with the data.

n	25
Age (years)	32.4 ± 6.0
Height (cm)	182.4 ± 37.1
Weight (kg)	79.7 ± 23.5
BMI (kg/m^2)	23.9 ± 2.0
Dominant arm (*L/R*)	*L* = 3/*R* = 22

Denmark, from December 2015 to February 2016. Data from one subject were discarded due to technical reasons. Anthropometrics from the participants are presented in Table 1. Inclusion criteria were healthy men between 18 and 60 years. Exclusion criteria were hypertension, i.e. blood pressure above 160/100 mm Hg, former blood clot or other serious heart disease, or back injury, e.g. herniated disc. Before enrolment of participants, the local ethical committee of Frederiksberg and Copenhagen approved the study (H-3–2010-062). The study followed the Declaration of Helsinki, and all participants received information on the content and purpose of the study before giving their written consent to participate.

2.2. Instrumentation

2.2.1. Electromyography

The subjects' skin was cleaned to lower the skin impedance before positioning the sEMG electrodes. For that purpose, the skin was shaved and scrubbed using scrubbing gel (Acqua gel, Meditec, Parma, Italy) and finally cleaned using surgical alcohol. The sEMG electrodes (Blue Sensor N-00-S/25, Ambu A/S, Ballerup, Denmark) (skin contact size 30*20 mm) were positioned with an inter-electrode distance of 2 cm (Hermens et al. 2000). The placement of the electrodes followed the SENIAM recommendations (http://www.seniam.org/); for the upper trapezius muscles the electrodes were placed at 50% on the line from the acromion to the spine on vertebra C7 and for the erector spinae muscles the electrodes were placed laterally from the spinous process of L1 corresponding to a two-finger width (approximately 2.5 cm). The reference electrode was placed over the c7 vertebra. The electrodes and the cables were secured using stretch tape (Fixomull stretch). sEMG signals were amplified 19.5 times using a portable 24 bit data-logger (Nexus10, Mind Media, Netherlands) and sampled at 1024 Hz.

2.2.2. Kinematics

Two accelerometers (ActiGraph GT9X Link, ActiGraph, Pensacola, USA) were placed on the upper back at the level of T1-T2 (Korshøj et al. 2014) and on the lower back at the level of L5 (Cleland et al. 2013), and they were fixed using stretch tape (Fixomull stretch). The accelerometers were initiated to sample at a sampling rate of 100 Hz using the manufacturer's software (ActiLife version 6.13.1). After positioning of the accelerometers, the subject quietly stood in a reference position with the arms along the side of the body (N-pose) for 15 s (Skotte et al. 2014) while the accelerometer readouts were registered. This was done to register the initial orientation of the accelerometers prior to the lifting.
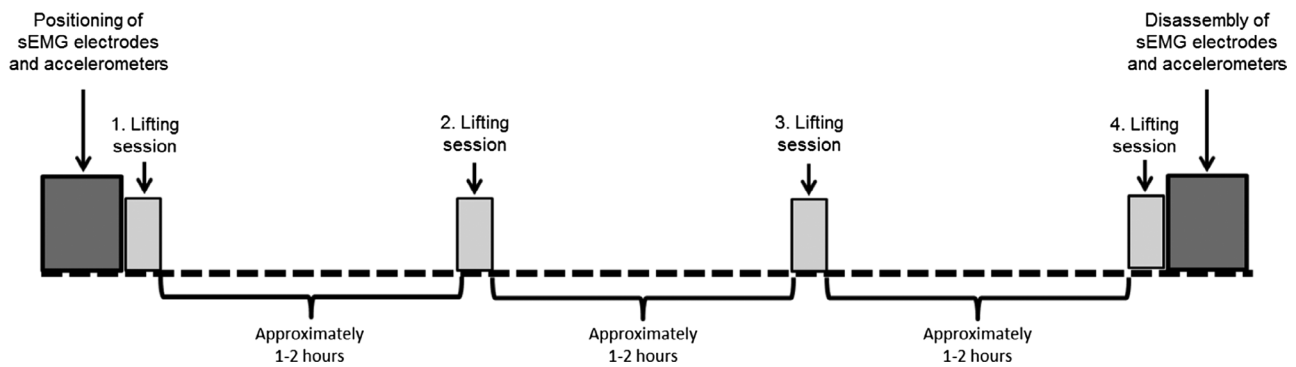
2.3. Synchronisation of measuring devices

To synchronise the recordings from the accelerometers and the sEMG logger, the initiation and the end of data recording were landmarked in both systems. Two custom made devices simultaneously turned the accelerometers 95° using a rotary solenoid (GDAX 050 X20 B71 24 V 100% ED) and triggered the sEMG data logger using a 2 V analogue output.

2.4. Study protocol

The lifting protocol was repeated four times during a day with approximately one to two hours between each lifting session (Figure 1). The subjects continued their daily work between the lifting sessions while wearing the sEMG electrodes and accelerometers. The lifting protocol consisted of lifts with the load at forearm distance (short distance) (Figure 2), ¾ arm distance (long distance) (Figure 2) and asymmetric lifts (Figure 3). For the lifts with short and long distance, the participants lifted a box (W: 56 cm, L: 34 cm, H: 20 cm) from the floor to a table (height 73 cm). From an upright starting position, the participants lifted the box from the floor before they took a step forward to place the box on the table. After a one second pause, they lifted the box back to the floor and returned to the starting position. For the asymmetric lifting condition, the participants lifted a kettlebell with their right arm. From a starting position standing upright, the participants lifted the kettlebell from the floor and back to the starting position carrying the load. After a one second pause, they lowered the kettlebell back to the floor and returned to the starting position (Figure 3). The lifting distances were standardised by tape markings. For the short distance, the loads lifted were 16, 18, 20, 22 and 24 kg and for the long distance the load was 16 kg. For the asymmetric lifting, the loads were 8, 12 and 16 kg. The loads lifted were based on recommendations from The Danish Working Environment Authority (Arbejdstilsynet 2005). According to these guidelines, lifts up to 30 kg under perfect lifting
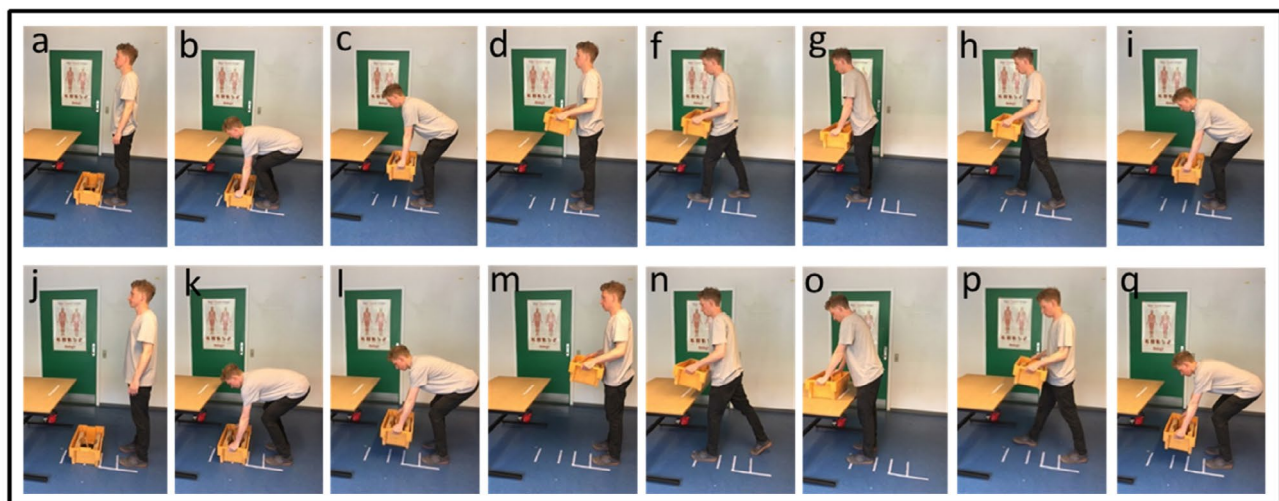
Figure 2. Lifting phases for lifting with short distance (a–i) and long distance (j–q), respectively. (a and j) start and end position, (b and k) pick-up of the box, (c and l) middle of the upward movement, (d and m) top of the upward movement, (f and n) stepping forward towards the table, (g and o) placing the box on the table, (h and p) stepping backwards, (I and q) lowering of the box.
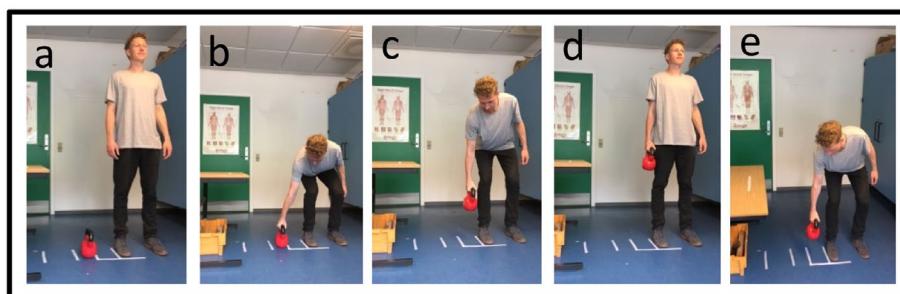
Figure 3. Lifting phases for asymmetric lifting. (a) Starting position, (b) pick up of the load, (c) middle of the upward movement, (d) top of the upward movement and (e) lowering of the load.

Table 2. Confusion matrix of the LDA classifying all the lifting types across all 100 random resampling procedures.

		Classified into								
		16 kg, SD	18 kg, SD	20 kg, SD	22 kg, SD	24 kg, SD	16 kg, LD	8 kg, AS	12 kg, AS	16 kg, AS
90th										
Original class	16 kg, SD	39.7 (9.1)	10.7 (7.1)	10.2 (7.0)	10.2 (6.3)	8.6 (4.9)	14.1 (6.0)	0.9 (1.7)	3.2 (3.0)	2.3 (2.5)
	18 kg, SD	43.4 (7.5)	5.9 (4.2)	9.4 (5.4)	10.5 (6.3)	11.1 (5.6)	13.9 (5.7)	0.8 (1.4)	3.1 (3.3)	2.0 (2.4)
	20 kg, SD	38.0 (6.3)	7.4 (5.2)	6.1 (4.0)	13.0 (6.9)	12.1 (6.7)	17.1 (7.2)	0.5 (1.1)	2.4 (2.8)	3.4 (2.8)
	22 kg, SD	35.6 (7.1)	6.2 (4.5)	10.4 (6.4)	8.7 (5.5)	16.5 (7.9)	19.2 (7.5)	0.0 (0.3)	1.2 (1.8)	2.2 (2.3)
	24 kg, SD	34.3 (7.8)	6.7 (4.6)	8.8 (5.7)	10.4 (7.7)	14.8 (7.1)	20.8 (9.6)	0.1 (0.4)	1.5 (2.1)	2.6 (2.7)
	16 kg, LD	37.0 (6.8)	5.3 (4.6)	7.4 (4.5)	9.5 (5.9)	15.8 (10.3)	18.6 (7.0)	0.0 (0.0)	0.4 (1.1)	5.9 (3.6)
	8 kg, AS	27.0 (6.9)	0.4 (1.0)	0.1 (0.4)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	36.2 (9.2)	23.1 (7.4)	13.3 (6.2)
	12 kg, AS	27.1 (7.4)	0.8 (1.4)	0.6 (1.4)	0.0 (0.0)	0.0 (0.0)	0.1 (0.6)	23.3 (7.5)	18.2 (7.1)	29.9 (8.0)
	16 kg, AS	25.5 (6.1)	0.5 (1.2)	0.2 (0.8)	0.0 (0.3)	0.1 (0.4)	0.2 (0.8)	13.6 (6.6)	17.7 (6.5)	42.1 (7.8)
95th										
Original class	16 kg, SD	44.6 (8.9)	8.6 (6.1)	8.0 (5.5)	10.5 (6.1)	7.7 (5.1)	13.8 (6.8)	2.4 (2.7)	2.9 (2.4)	1.6 (2.2)
	18 kg, SD	44.1 (7.9)	5.9 (4.1)	8.3 (5.7)	10.0 (6.3)	9.8 (5.5)	13.5 (6.1)	2.0 (2.5)	3.3 (2.9)	3.0 (2.7)
	20 kg, SD	37.0 (7.2)	7.3 (4.6)	4.5 (3.9)	10.6 (6.9)	14.2 (7.4)	17.6 (7.9)	0.9 (1.5)	2.9 (2.6)	5.0 (3.2)
	22 kg, SD	35.3 (7.6)	5.7 (4.2)	8.9 (5.2)	6.3 (4.4)	16.9 (7.8)	20.1 (7.5)	0.7 (1.5)	2.3 (2.5)	3.9 (2.8)
	24 kg, SD	33.5 (7.5)	5.3 (3.8)	7.8 (5.7)	10.0 (6.8)	12.9 (7.2)	24.1 (10.7)	0.0 (0.0)	2.1 (2.4)	4.3 (3.8)
	16 kg, LD	35.2 (6.3)	3.6 (3.6)	5.4 (4.4)	10.2 (6.1)	17.5 (8.5)	20.0 (6.8)	0.0 (0.0)	0.8 (1.5)	7.3 (3.6)
	8 kg, AS	26.9 (5.4)	0.7 (1.3)	0.0 (0.3)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	36.1 (6.9)	25.3 (8.2)	11.0 (5.9)
	12 kg, AS	26.6 (6.1)	1.6 (2.1)	0.5 (1.3)	0.0 (0.3)	0.0 (0.3)	0.1 (0.4)	26.2 (8.0)	18.0 (5.4)	27.0 (6.9)
	16 kg, AS	25.3 (6.6)	0.9 (1.6)	0.4 (1.0)	0.1 (0.6)	0.1 (0.4)	0.6 (1.3)	15.6 (7.0)	15.8 (6.9)	41.2 (7.7)
99th										
Original class	16 kg, SD	41.1 (8.6)	10.8 (5.8)	9.5 (5.4)	9.1 (5.1)	6.8 (4.0)	13.8 (7.4)	4.0 (3.7)	3.1 (3.3)	1.8 (2.5)
	18 kg, SD	42.2 (7.9)	5.6 (4.0)	9.5 (5.2)	9.2 (5.4)	10.8 (5.7)	15.3 (6.8)	3.3 (3.1)	2.1 (2.3)	2.1 (2.3)
	20 kg, SD	35.0 (7.7)	7.0 (5.0)	4.7 (4.0)	9.5 (6.2)	14.0 (6.1)	20.2 (7.6)	1.5 (1.9)	2.3 (2.8)	5.8 (3.7)
	22 kg, SD	34.9 (7.6)	4.8 (3.7)	8.1 (4.8)	4.5 (3.6)	17.2 (7.5)	23.0 (8.1)	1.2 (1.6)	0.8 (1.3)	5.5 (3.4)
	24 kg, SD	30.9 (6.5)	5.1 (4.1)	8.2 (5.4)	11.1 (7.2)	13.2 (6.4)	26.4 (8.8)	0.9 (1.7)	0.4 (1.1)	3.9 (3.0)
	16 kg, LD	33.3 (7.2)	4.0 (3.1)	9.1 (5.1)	7.9 (5.8)	16.5 (8.8)	22.6 (7.0)	0.5 (1.2)	0.6 (1.5)	5.4 (3.8)
	8 kg, AS	28.7 (6.4)	1.6 (1.9)	0.5 (1.2)	0.2 (0.8)	0.0 (0.3)	0.4 (1.2)	33.7 (7.7)	23.2 (8.5)	11.6 (4.9)
	12 kg, AS	26.8 (7.4)	0.3 (0.9)	0.7 (1.7)	0.1 (0.4)	0.1 (0.5)	0.3 (1.0)	28.2 (8.6)	17.5 (6.2)	26.0 (7.9)
	16 kg, AS	24.5 (6.4)	0.5 (1.2)	0.8 (1.5)	0.1 (0.5)	0.1 (0.4)	0.8 (1.4)	17.5 (6.8)	15.2 (6.4)	40.4 (7.5)

Notes: The numbers are in percentage and presented as mean (SD). SD = short reaching distance (forearm length), LD = long reaching distance (3/4 arm length), AS = asymmetric lifting (all performed with right arm).
The grey shading indicates values where the classified values equals the original class.

conditions are considered low risk lifts. As the load in this study was lifted from the floor and not from an optimal height, this was considered an aggravating factor and the allowed load was reduced.

Each load for each lifting condition was performed as a set of three consecutive lifts (a lifting trial) with a small pause of approximately 4–5 s between each repetition. Each lifting trail was performed in a slow, controlled manner without any sudden jerks and accelerations. The test leader visually inspected all lifts and repeated the recording of the lift if it was performed in an uncontrolled manner. Before and after each lifting trial, the subjects were quietly standing for at least 5 s.

The order of the lifts was randomised and counterbalanced across the subjects and was the same in the four lifting sessions, i.e. the lifts were performed in the same order in all four sessions. In practice, the randomisation was conducted by the subject drawing an unmarked envelope containing the protocol with the order in which the lifts were to be performed.

Before and after the lifting protocol, the participants performed three maximal voluntary isometric contractions (MVIC) for the shoulder and low back muscles. For the trapezius muscles, the subjects performed a 90° bilateral shoulder abduction by pushing against resistance from the test leader. For the erector spinae muscles, the

Table 3. Confusion matrix of the LDA identifying the low and high-risk lifts, presented in % (± SD).

				Classified into				
	90th	Low	High	95th	Low	High	99th	Low	High
Original	Low risk	24.3 (3.7)	75.7 (3.7)		22.4 (3.9)	77.6 (3.9)		18.9 (4.5)	81.1 (4.5)
	High risk	14.4 (2.4)	85.6 (2.4)		13.7 (2.9)	86.3 (2.9)		12.7 (3.1)	87.3 (3.1)

subjects were placed lying prone in an approximately 20-degree angle in a customised device that supported the subjects' legs and hips. From a position with a slightly flexed hip, the subjects pushed upwards against the test leader's static resistance. The participants were allowed to perform sub-maximal test trials for familiarisation and warm up before the MVICs were obtained (Konrad 2005).

2.5. Data analysis

After segmenting sEMG and accelerometer signals over a 30 s window starting approximately 2 s before the lifting tasks, the root mean square (RMS) of sEMG signals was calculated over a 500 ms epoch with a 20% overlap between successive epochs and normalised to the maximum RMS obtained during the MVIC trials. When the movement acceleration is negligible in comparison to the gravitational acceleration, the accelerometer output can be used to derive the inclination of the sensor, and for this reason we asked the subjects to perform the lifts without sudden jerks or accelerations. Thus, if the deviation of the modulus of the acceleration vector was less than 20% of the gravitational acceleration, the forward and sideways inclination of the accelerometer with respect to the N-pose reference position was calculated (Skotte et al. 2014). The missing samples (less than 5% of the samples in each lift) due to the deviation of the modulus of the acceleration vector were linearly interpolated within each lift.

In light of the studies investigating the effect of physical exposure (Jonsson 1982), the 90th, 95th and 99th percentiles of calculated EMG RMS from the four recorded muscles and the forward and sideways inclination considering the direction of inclination were derived and composed the feature vector revealing the loading pattern in each of the lifting tasks. Thus, the feature vector composed of eight elements (four EMG RMS values, two forward and two sideways inclination values) characterised a lifting trial. The obtained results were used to conduct a sensitivity analysis using thresholds corresponding to the 90th, 95th and 99th percentiles.

The lifting types were categorised into two overall groups posing a high or a low risk according to the occupational guidelines (Arbejdstilsynet 2005) as explained above. The liftings performed at short distance with 16, 18 and 20 kg load were considered low risk, and the rest of the lifts, i.e. 22 and 24 kg, at short distance, 8, 12 and 16 kg asymmetric lifts, and 16 kg with long reaching distance were considered high risk events. LDA was performed to classify the lifting types. In addition, LDA was also used to discriminate between low and high risk lifts. In each case, two-thirds of the derived feature vectors were utilised to train the classifier, meaning that the optimal borders between the lifting types were determined based on the obtained feature vectors. The rest of the feature vectors were used to test the accuracy of the classification. This procedure was repeated 100 times by randomly sampling the training and test set (Monte-Carlo cross validation (Xu and Liang 2001)). Then the average and standard deviation of the classification accuracy was obtained. A greedy forward selection of features was performed to find the most effective elements of the feature vector to identify the lifting types.

Additionally, a subject-specific threshold was derived by taking the maximum of EMG RMS (EMG thresholds) and maximum sideways inclination (inclination threshold) of the accelerometer across the repetitions of the lifting at short distance with a 20 kg load. Thus, the events were identified by a simple thresholding approach. For each subject, if more than one of the registered EMG RMS in the feature vector were above their corresponding EMG threshold or if the sideway inclination of the trunk was above the inclination threshold, the lift was considered a high risk trial. The accelerometers attached to the lower and the upper back were used in this approach; one at a time to compare the effectiveness of the information derived to characterise the lifting types.

Table 4. Confusion matrix when the low and high risk liftings were identified based on the subject-specific threshold based on the lower back accelerometer, presented in %.

				Classified into				
	90th	Low	High	95th	Low	High	99th	Low	High
Original	Low risk	90	10		90	10		88	12
	High risk	58	42		61.3	38.7		65.8	34.2

Table 5. The error rate (%) for each subject based the lower back accelerometer.

		Sbj1	Sbj2	Sbj3	Sbj4	Sbj5	Sbj6	Sbj7	Sbj8	Sbj9	Sbj10	Sbj11	Sbj12	Sbj13	Sbj14	Sbj16	Sbj17	Sbj18	Sbj19	Sbj20	Sbj21	Sbj22	Sbj23	Sbj24	Sbj25	Sbj26
90th	Low	0	8	25	17	8	0	8	0	25	17	17	8	8	0	17	8	25	0	0	17	0	25	8	8	0
	High	75	75	75	58	63	50	88	96	38	54	58	83	54	38	38	79	50	29	79	54	25	54	63	54	21
95th	Low	0	17	33	25	0	0	8	17	17	8	0	8	17	17	33	0	8	17	8	8	0	8	0	0	0
	High	79	63	67	46	67	67	88	100	50	63	67	96	67	38	38	79	46	46	71	54	33	71	71	63	8
99th	Low	17	33	42	0	0	0	0	0	25	0	17	0	25	8	0	0	0	17	50	25	0	8	17	8	8
	High	88	54	46	67	71	67	75	100	58	67	54	96	54	38	46	92	54	42	71	71	50	79	67	96	46

Notes: The first row shows the percentage of identifying a low risk lift as a high risk lift for each subject. Please note that Subject 15 was discarded due to technical problems with the data.

3. Results

Data from one subject were discarded due to technical reasons (poor data quality). The results from the sensitivity analysis showed no clear difference between the 90th, 95th and 99th percentile thresholds. The confusion matrix of the LDA classifying all the lifting types across all 100 random resampling procedures shows an average accuracy of the classification of 21.2% (2.1), 20.9% (2.1) and 20.3% (1.9) for the 90th, 95th and 99th percentile, respectively (Table 2). Table 3 shows the confusion matrix of the LDA when it was applied to discriminate between the low and high risk lifts. The average accuracy of the classification was 65.1% (1.8), 65.0% (1.9) and 64.5% (1.7) for the 90th, 95th and 99th percentile, respectively. The greedy forward selection showed that upper back sideways inclination and the EMG RMS obtained from the right trapezius are the most discriminative features without a noticeable compromise in the classification accuracy. When the low and high risk lifts were identified based on the subject-specific threshold using the lower back accelerometer, the confusion matrix showed an accuracy of identifying the low and high risk lifts of 58.1, 55.7 and 52.1% for the 90th, 95th and 99th percentile, respectively (Table 4). Table 5 shows the error rate (% of all the performed lifts) for each subject. The accuracy was 78.1, 76.4 and 72.7% for the 90th, 95th and 99th percentile, respectively, when identifying the low and high risk lifts using the subject-specific threshold based on sEMG and back inclination based on the accelerometer on the upper back (Table 6). The error rate (%) for each subject is presented in Table 7.

4. Discussion

This study shows that using a subject-specific threshold from sEMG and inclination of the upper back the LDA provides an accuracy of 78.1, 76.4 and 72.7% for the 90th, 95th and 99th percentile, respectively, in identifying low or high risk lifts during a standardised protocol. Due to inconsistencies in the literature, we tested the accuracy using the 90th, 95th and 99th percentiles. Because the results were broadly similar, we have chosen to use the 95th percentile in the remaining part of the discussion section. The accuracy was lower when using the subject-specific threshold

of inclination from the low back and when using the LDA with categories of high and low risk, i.e. 55.7 and 65.0% of accuracy, respectively.

A study by Faber et al. (2009) recommends a single inertial sensor placement for measuring back inclination of around 25% of the distance from the midpoint between the posterior superior iliac spines to the C7 spinous process (Faber et al. 2009). Even though the placement of the accelerometer on the upper back at the level of T1-T2 in the present study is slightly higher than in Faber et al. (2009), the results are in accordance with their recommendation. This aspect was further underlined by the lower classification accuracy using the subject-specific threshold from the low back accelerometer which classified the lift into low or high risk with an accuracy of 65%.

Only limited knowledge exists regarding classification of lifts into low and high risk or classification of risks of low back disorders. A study tested the ability of LDA classifiers to predict the risk of low back disorders due to workplace design in industrial jobs with an accuracy of 73% (Ganga, Esposto, and Braatz 2012). This may call for the application of data mining techniques to pinpoint the high risk events in ergonomics studies and promise a useful approach to monitor the physical load in field studies.

Compared with previous studies using either sEMG or accelerometer data, the advantage of the methods used in the present study is that it includes both sEMG and kinematics in the detection of situations in which the worker is exposed to high physical loads which are potentially hazardous. Furthermore, the use of individual values was shown to be extremely important in terms of upper back inclination and sEMG since this provides the possibility of a worker-specific objective measure of the physical load during work measured with sEMG and kinematics. As such, the use of subject-specific values has been suggested to be preferable (Balogh et al. 1999). The present results can contribute to the development of methods for objectively detecting high risk lifting tasks during which the worker is exposed to high biomechanical loading based on individual sEMG and kinematics obtained during an entire working day. We have previously tested the interday test-retest reliability of sEMG during standardised lifting (Brandt et al. 2017). The results have shown that

Table 6. Confusion matrix when the low and high risk liftings were identified based on the subject-specific threshold based on the upper back accelerometer, presented in %.

		Classified into							
		90th	Low	High	95th	Low	High	99th	Low	High
Original	Low risk		86.3	13.7		85.5	14.3		85	15
	High risk		26	74		28.2	71.8		33.5	66.5

Table 7. The error rate (%) for each subject based on the upper back accelerometer.

		Sbj1	Sbj2	Sbj3	Sbj4	Sbj5	Sbj6	Sbj7	Sbj8	Sbj9	Sbj10	Sbj11	Sbj12	Sbj13	Sbj14	Sbj16	Sbj17	Sbj18	Sbj19	Sbj20	Sbj21	Sbj22	Sbj23	Sbj24	Sbj25	Sbj26
90th	Low	0	0	8	33	25	8	17	33	17	25	0	8	0	17	8	17	0	17	42	8	0	17	0	25	17
	High	71	29	50	13	13	0	50	17	38	17	8	29	21	42	33	33	8	17	67	13	13	25	17	4	25
95th	Low	0	17	25	25	17	17	25	8	17	25	8	8	0	33	17	0	25	17	33	0	0	8	8	0	25
	High	83	17	38	29	17	17	83	29	29	33	21	29	33	29	17	38	0	25	50	8	8	33	21	13	4
99th	Low	17	17	17	17	8	0	17	0	17	25	33	17	25	42	8	0	8	0	17	33	8	25	0	0	25
	High	88	17	38	29	21	29	79	42	29	29	25	13	4	29	38	67	17	33	58	21	25	29	21	33	25

Notes: The first row shows the percentage of identifying a low risk lift as a high risk lift for each subject. Please note that Subject 15 was discarded due to technical problems with the data.

sEMG during a standardised lifting situation has a fair to substantial relative reliability of 89% and 73% of the lifting situations in absolute sEMG and normalised sEMG, respectively. However, reliability studies do not address the question of validity or accuracy (Pazira et al. 2016). The current study is part of the method development for an intervention study in the construction industry measuring the construction workers' physical loading and body positions using sEMG and accelerometers, respectively (Brandt et al. 2015). The relatively high accuracy (76.4%) using the subject-specific threshold in identifying low or high risk lifts during occupational lifting is promising and the method can be used in field studies to identify high risk lifting events.

5. Strength and limitations

The strength of this study is related to the sole use of an objective analytic method to detect potentially hazardous lifts during work-related lifting. The main limitation of the current study is related to the fact that all lifts were standardised in a laboratory environment among young asymptomatic males. Additionally, the lifting events in the current study had quite a well-defined onset and offset. In field studies, the onset and offset should be determined based on scrutinising the timeline of the task with a fine temporal resolution. Therefore, the reported accuracy cannot be extrapolated to older workers or workers with low back pain.

6. Conclusion

This study showed that it is possible to identify lifting situations that pose a low or high risk for development of low back disorders with an accuracy of 78.1, 76.4 and 72.7% for the 90th, 95th and 99th percentile, respectively. The analysis used sEMG activity of the upper trapezius and erector spinae muscles and the inclination of the upper trunk to define subject-specific thresholds. This approach opens perspectives for the automatic detection of lifts associated with hazards and leading to low back injury, which has the potential to be more cost-effective than visual observations.

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