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ORIGINAL ARTICLE

Basic Study

Neuromuscular trunk activation patterns in back pain patients during one-handed lifting

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Abstract

AIM

To analyze neuromuscular activity patterns of the trunk in healthy controls (H) and back pain patients (BPP) during one-handed lifting of light to heavy loads.

METHODS

After assessment of back pain (graded chronic pain scale according to von Korff) all subjects (n = 43) performed a warm-up (treadmill walking). Next, subjects were instructed to lift 3 × a 20 kg weight placed in front of them (with both hand) onto a table (height: 0.75 m). Subsequently, all subjects lifted with one hand (left-side, 3 repetitions) a weight of 1 kg (light), 10 kg (middle) and 20 kg (heavy) in random order from the ground up onto the table left of them. Trunk muscle activity was assessed with a 12-lead EMG (6 ventral/6 dorsal muscles; 4000 Hz). EMG-RMS (%) was averaged over the 3 repetitions and analyzed for the whole one-handed lifting cycle, then normalized to RMS of the two-handed lifting. Additionally, the mean (normalized) EMG-RMS of four trunk areas [right/left ventral area (VR/VL); right/left dorsal area (DR/DL)] was calculated. Data were analyzed descriptively (mean ± SD) followed by student's t-test comparing H and BPP (α = 0.05). With respect to the unequal distribution of subjects in H and BPP, a matched-group analysis was conducted. Seven healthy controls were gender- and age-matched (group $H_{matched}$) to the 7 BPP. In addition, task failure was calculated and compared between H/$H_{matched}$ *vs* BPP using χ^2.

RESULTS
Seven subjects (3m/4f; 32 ± 7 years; 171 ± 7 cm; 65 ± 11 kg) were assigned to BPP (pain grade ≥ 2) and 36 (13m/23f; 28 ± 8 years; 174 ± 10 cm; 71 ± 12 kg) to H (pain grade ≤ 1). H and BPP did not differ significantly in anthropometrics (P > 0.05). All subjects were able to lift the light and middle loads, but 57% of BPP and 22% of H were not able to lift the heavy load (all women). χ^2 analysis revealed statistically significant differences in task failure between H *vs* BPP (P = 0.03). EMG-RMS ranged from 33% ± 10%/30% ± 9% (DL, 1 kg) to 356% ± 148%/283% ± 80% (VR, 20 kg) in H/BPP with no statistical difference between groups regardless of load (P > 0.05). However, the EMG-RMS of the VR was greatest in all lifting tasks for both groups and increased with heavier loads.

CONCLUSION
Heavier loading leads to an increase (2- to 3-fold) in trunk muscle activity with comparable patterns. Heavy loading (20 kg) leads to task failure, especially in women with back pain.

Key words: Lifting; Core; Trunk; EMG; MISPEX

Core tip: The aim of this study was to analyze neuromuscular activity patterns of the trunk in healthy controls (H) and back pain patients (BPP) during one-handed lifting of light to heavy loads. Neuromuscular trunk compensation strategies for expected loading with different weights did not differ between BPP and H, and showed a similar muscular activation pattern with the highest activity found in the contralateral abdominal muscles (VR). Heavier loading leads to an increase (2- to 3-fold) in trunk muscle activity with comparable patterns between groups. Heavy loading (20 kg) may lead to task failure, especially in women with back pain.

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INTRODUCTION

Back pain places a large burden on the societies and healthcare systems of western industrialized nations with high direct (*e.g.*, therapy measures) and indirect costs (*e.g.*, loss of working hours)[1-3]. Hence, research to develop approaches for the prevention and/or rehabilitation of back pain is extremely interesting and could have a very beneficial effect. Consequently, the investigation of differences in trunk function between people with and without back pain is of primary interest in order to define adequate therapy and/or prevention strategies.

In etiology, repetitive micro-trauma, as well as insufficiency of the muscle-tendon complex based on inadequate postural and neuromuscular control, reduced maximum trunk strength capacity and trunk muscle fatigue during dynamic loading, have been supposed[4,5]. Thus, an altered neuromuscular activity of the trunk muscles is already evident in back pain patients (BPP)[6-12]. Longer response times[6,12], altered recruiting or activation patterns[8,11,12], extended activation times[7] and increased co-contractions[10,11] have been described in affected patients[13]. However, these differences are only valid in situations where the load is applied rapidly or suddenly either directly to the trunk or to the upper/lower limbs. Nevertheless, these situations are often limited in representing daily life activities which is highly comprised of lifting tasks. Since lifting tasks are omnipresent in daily life and correspond with an automated movement pattern, they seem expedient for the comparison of trunk muscle activity pattern between H and BPP.

In terms of lifting tasks, McGill *et al*[14] investigated the influence of different loads (5, 10, 15, 20, 30 kg) and carrying conditions (one-handed *vs* two-handed) on low back load. One-handed carrying led to greater low back loads compared to two-handed carrying of the same weight due to an increased shear stress on the spine. Therefore, one-handed lifting proposes a more challenging situation compared to two-handed lifting. Moreover, different loads might provoke different muscular activation patterns of the trunk and its regions as part of the compensation strategy of the trunk, even in healthy controls.

Nevertheless, it is ultimately unclear whether BPP suffer from altered trunk neuromuscular activity during expected, continuous loading, while lifting different loads. Therefore, the aim of this study is to analyze neuromuscular activity patterns of the trunk in healthy controls (H) and BPP during one-handed lifting with different loads. It is hypothesized that both healthy controls (H) and BPP will show increased trunk muscle activity with heavier loads, especially for muscles opposite the lifting hand. In addition, BPP might show increased activity and an altered activation pattern compared to healthy controls to compensate for pain. Consequently, this trunk muscle activation analysis could help define adequate therapy and/or prevention strategies for back pain.

MATERIALS AND METHODS

Subjects

Forty-eight subjects were initially recruited and explained the procedures by the study coordinator. Forty-three (16m/27f; 29 ± 7 years; 174 ± 10 cm; 70 ± 12 kg)

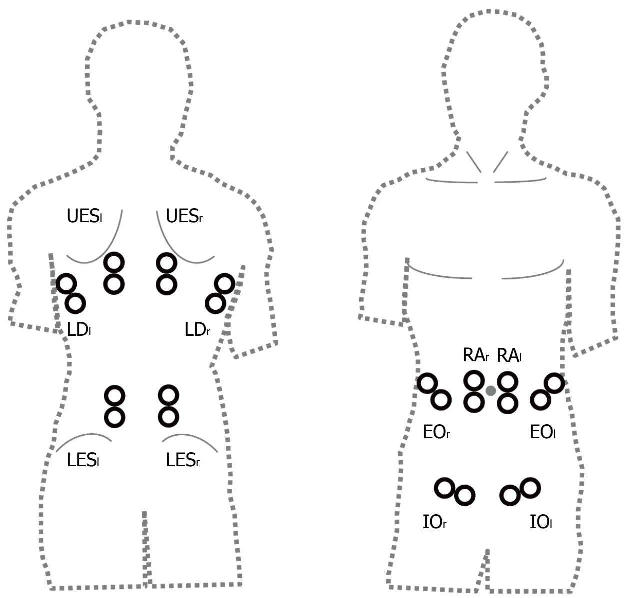

Figure 1 12-lead EMG trunk-setup. Single muscles: $RA^{ri/le}$: M. rec. abd. right/left; $EO_{ri/le}$: M. obl. ext. abd. right/left; $IO_{ri/le}$: M. obl. int. abd. right/left; $LD_{ri/le}$: M. latis. dorsi right/left; $UES_{ri/le}$: M. erec. spinae thoracic (T9) right/left; $LES_{ri/le}$: M. erec. spinae lumbar (L3) right/left.

subjects agreed to participate and formally gave written informed consent before voluntary participation. The University's Ethical Commission approved the study.

With respect to the unequal distribution of subjects included in H and BPP, an additional matched-group analysis was conducted. Therefore, an equal number of healthy controls were gender-, age- and anthropometrically matched (group $H_{matched}$) to the number of BPP.

Measurement protocol

Initially, all participants answered an online-based (Pro WebDB, Germany) version of a back-pain questionnaire (von Korff) determining the presence of back pain[15]. Next, subjects were prepared for electromyographic measurements of the trunk. Before the lifting tasks, every subject performed a 5-min warm-up (treadmill walking). Subsequently, the lifting protocol started with a two-handed task, used as reference for EMG-normalization. Therefore, subjects lifted a 20 kg weight from the ground up and onto a table (height: 0.75 m) being positioned in front of them three times. Afterwards, all subject performed exclusively one-sided left-handed liftings. In random order, three times each, subjects lifted a light (1 kg), a middle (10 kg) and a heavy (20 kg) load with the left hand from the ground up and onto a table (height: 0.75 m). The table was positioned on the left side of the subjects. Subjects began all lifting tasks in an identical neutral position (hip-width bipedal upright stance) and were instructed to lift the load with a self-selected moderate speed, starting with slight bending of the knees and the trunk. Each lifting task was first demonstrated by the examiner, then subjects performed one test trial before starting the measurement.

Back pain questionnaire

The back pain questionnaire consisted of 7 items, including pain intensity and disability (acute and last 3 mo)[15]. Six out of seven items are analyzed by a numeric rating scale ranging from 0 (no pain/disability) to 10 (highest pain/disability). Based on the grading score of the questionnaire, subjects were assigned to the healthy control group (H; Korff grades 0 and 1) or back pain patient group (BPP; Korff grades 2-4). Back pain prevalence was calculated based on this group assignment.

EMG analysis

Trunk muscle activity was assessed by means of a 12-lead surface EMG[12] including six ventral [Mm rectus abdominis (RA), obliquus externus abdominis (EO), obliquus internus abdominis (IO) of left and right side] and six dorsal [Mm erector spinae thoracic (T9; UES)/lumbar (L3; LES), latissimus dorsi (LD) of left and right side] muscles (Figure 1). Muscular activity was analyzed using bilateral, bipolar surface EMG (bandpass filter: 5-500 Hz; sampling frequency: 4000 Hz, amplification: overall gain: 1000; myon, Switzerland). Before electrodes were applied (AMBU Medicotest, Denmark, Type N-00-S, inter-electrode distance: 2 cm), the skin was shaved, slightly exfoliated to remove surface epithelial layers and finally disinfected. In addition, skin resistance was measured and controlled to be less than 5 kΩ. The longitudinal axes of the electrodes were aligned with the presumed direction of the underlying muscle fibers.

The mean amplitude of the whole lifting cycle (average of 3 repetitions) was calculated for all lifting loads (1, 10, 20 kg). As a main outcome measurement, the one-handed lifting root mean square [EMG-RMS; (%)] normalized to EMG-RMS of the two-handed lifting task (with 20 kg) was calculated. In addition, the mean (normalized) EMG-RMS for muscle groups was calculated and therefore averaged of the EMG-RMS of the three single muscles per group: right ventral area ((VR: RA, EO, IO of right side), left ventral area (VL: RA, EO, IO of left side), right dorsal area (DR: UES, LES, LD of right side) and left dorsal area (DL: UES, LES, LD of left side)[12].

Statistical analysis

All non-digital data were documented in a paper and pencil-based case report form (CRF) and transferred to a statistical database (JMP Statistical Software Package 9, SAS Institute®). After plausibility checks, data was analyzed descriptively (means, SD) for all given outcome measures followed by student's *t*-tests to investigate for differences between H and BPP. The level of significance was set α = 0.05. In addition, task failure was calculated and compared between H ($H_{matched}$) *vs* BPP using χ^2. Multiple testing was controlled *via* Bonferroni adjustment (*e.g.*, 4 muscle groups: *P* = 0.01; 12 single muscles: *P* = 0.004). In addition, the statistical review of the study was performed by a

Table 1 Anthropometrics and back pain status of healthy controls (H; $H_{matched}$) and back pain group

Group	*n*	Gender (f/m)	Age (yr)	Body weight (kg)	Body height (cm)	Pain Intensity score[b,d]	Disability score[b,d]	Korff grade
H	36	23/13	28 ± 8	71 ± 12	174 ± 10	16 ± 11	7 ± 12	0.9 ± 0.3
BPP	7	4/3	32 ± 7	65 ± 11	171 ± 7	50 ± 17	43 ± 10	2.6 ± 0.8
$H_{matched}$	7	4/3	30 ± 7	64 ± 6	170 ± 9	15 ± 9	6 ± 9	1.0 ± 0.0

[b]Significant differences between H and BPP (P < 0.001); [d]Significant differences between $H_{matched}$ and BPP (P < 0.001). BPP: Back pain patients.

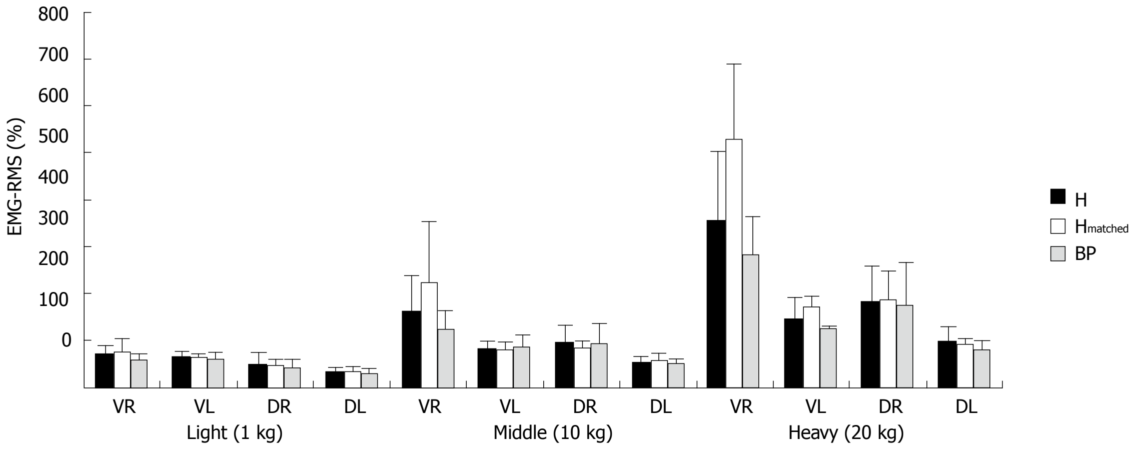

Figure 2 Neuromuscular activity (EMG-RMS; %) of trunk areas for healthy controls (H; $H_{matched}$) and back pain patients for the lifting tasks with 1, 10 and 20 kg (VR/VL: RA, EO, $IO_{ri/le}$; DR/DL: LD, UES, $LES_{ri/le}$). BPP: Back pain patients; VR/VL: Right/left ventral area; DR/DL: Right/left dorsal area.

biomedical statistician.

RESULTS

Back pain prevalence

Thirty-six subjects were allocated as healthy controls (H) and seven as BPP. This represents a back pain prevalence of 16% in the cohort analyzed. Anthropometrics and pain subscores (pain intensity/disability score) of both groups are presented in Table 1. Statistically significant differences between H and BPP were present in the pain subscores (P < 0.001), but not in anthropometrics.

Regarding matched-group analysis, seven healthy subjects were age- and gender-matched (group $H_{matched}$) to the seven BPP. Again, statistically significant differences between $H_{matched}$ and BPP were present in the pain subscores (P < 0.001), but not in anthropometrics.

Task failure

All subjects were able to lift the light (1 kg) and middle (10 kg) loads. However, 57% (n = 4) of BPP and 22% (n = 8) of H/29% of $H_{matched}$ (n = 2) were unable to lift the heavy (20 kg) load. All of them were female. χ^2 analysis revealed significant differences here between H and BPP (P = 0.03), but not for $H_{matched}$ *vs* BPP (P = 0.06).

Trunk muscle activity during lifting

In EMG-RMS analysis, no statistically significant group differences (BPP *vs* H; BPP *vs* $H_{matched}$) were found (P > 0.05) (Figure 2). However, H showed higher mean EMG-RMS compared to BPP in all four trunk areas analyzed (P > 0.05) (Figure 2).

EMG-RMS during lifting of the light load (1 kg) ranged between 33% ± 10% (DL) to 71% ± 18% (VR) for H, between 33% ± 9% (DL) to 76% ± 27% (VR) in $H_{matched}$ and between 30% ± 9% (DL) to 59% ± 11% (VR) in BPP. During lifting of the middle load (10 kg), EMG-RMS varied between 52% ± 12% (DL) to 161% ± 76% (VR) for H, between 58% ± 15% (DL) to 224% ± 129% (VR) in $H_{matched}$ and between 50% ± 11% (DL) to 124% ± 39% (VR) in BPP. Regarding high loading (20 kg), EMG-RMS ranged between 97% ± 30% (DL) to 356% ± 148% (VR) for H, between 92% ± 10% (DL) to 530% ± 157% (VR) in $H_{matched}$ and between 80% ± 19% (DL) to 283% ± 80% (VR) in BPP. Regardless of load, no significant differences in trunk muscle activity could be found between groups (P > 0.05).

Regardless, VR produced the greatest EMG-RMS during all lifting tasks in both groups. In addition, EMG-RMS increased in all four trunk areas with heavier loading, especially VR and DR muscle groups. The polar plot (Figure 3) shows the activation pattern of all 12 muscles comparing H ($H_{matched}$) and BPP.

In addition, matched group analysis did not show any significant differences between groups with regards to loading tasks (P > 0.05; BPP *vs* $H_{matched}$) (Figures 2 and 3).

DISCUSSION

The main purpose of this study was to analyze neuromuscular activity patterns of the trunk in healthy con-

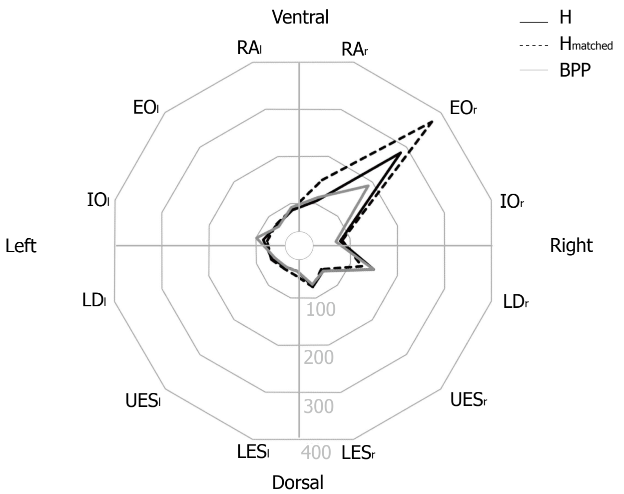

Figure 3 Polarplot of neuromuscular activity (EMG-RMS; %) of the 12 trunk muscles in healthy controls (H/$H_{matched}$) and back pain patients for lifting of middle load (10 kg).

trols (H) and BPP during one-handed lifting of different loads. This study demonstrates that BPP do not show an altered neuromuscular activity pattern, in terms of EMG amplitude, of the trunk during one-handed lifting of three different loads compared to healthy controls. Nevertheless, a significantly greater rate of task failure, while lifting heavy loads (20 kg), could be shown in BPP.

In contrast to the known alterations of the neuromuscular activation pattern of the trunk during suddenly applied loads[12,16], no significant differences in trunk muscle amplitudes could be shown between BPP and H ($H_{matched}$) during one-handed lifting of expected loads. This can be discussed in the context of the experimental task: lifting *vs* quick-release experiments. The used lifting task correlates to an expected, continuous loading of the trunk. It could be discussed that due to the knowledge of the task, as well as the low (1 kg) and middle (10 kg) lifting weight, BPP are able to use an adequate - comparable to healthy controls - activation strategy to perform the task despite pain. In contrast, frequently used quick-release experiments apply a sudden, unexpected load to either the trunk or the limbs[12,13,17]. In these studies, patients could not prepare themselves for the high loading and therefore showed altered neuromuscular activity pattern. However, lifting tasks are omnipresent in daily life, thus adequately represent functional movements. It could be speculated that the lifting pattern is an automated movement pattern, comparable to the human gait, and therefore BPP are able to reproduce an adequate neuromuscular activation pattern showing no difference to healthy controls. However, the presented EMG-RMS differences between H ($H_{matched}$) and BPP showed no statistical significance, but could be interpreted as clinically relevant with differences up to 250% between groups [*e.g.*, 530% ± 157% ($H_{matched}$) *vs* 283% ± 80% (BPP)]. Due to a high inter-individual variability and the small sample size, especially the low number of BPP, statistically significant differences would have been difficult to yield. Additionally, it should be mentioned that the acute pain level of the BPP group was actually quite low. In detail, it ranged between 0 and 8 on the numeric rating scale (0-10) (mean ± SD: 2.9 ± 2.5).

Despite finding no effect of back pain on neuromuscular activity patterns, lifting of a heavy load (20 kg) led to a significant increase in task failure in the BPP group, especially in women. The frequently observed trunk strength deficits in BPP could be a cause for the task failure at high loads (20 kg)[18]. In addition, task failure in women could correspond to the higher prevalence of back pain and reduced trunk stability in females documented by Schneider *et al*[19]. As a consequence, back pain therapy, especially in females, should focus on the preparation of adequate compensation of high loading (expected, continuous). Moreover, the results imply that an overall reduced performance capacity in BPP leads to task failure. Therefore, additional diagnostics are recommended, *e.g.*, strength assessment, to deliver individual therapy regimes.

Although BPP neuromuscular activity levels did not differ, both groups revealed a specific neuromuscular activity pattern of the trunk with muscle activity becoming more pronounced with rising load (20 kg). With increased loading, neuromuscular activity level also increased in all trunk muscles. In addition, the ventral muscle group (VR) ipsilateral to the side of the applied load (left hand) revealed the greatest activity during all loading conditions (1, 10, 20 kg). Therefore, a task-specific compensation strategy could be assumed in healthy controls and in BPP during continuous lifting of (expected) weights.

Certain limitations of the study, however, have to be considered. During the experiment, all participants lifted the same defined weights (1, 10, 20 kg) regardless of their body weight. In addition, a standardized table height (0.75 m) was used regardless of individual body height. These methods were chosen for comparability to certain daily life tasks, *e.g.*, carrying a crate full of bottles. Therefore, no individual adaptations were made. Additionally, giving instructions to the subjects as to how to lift the objects could have influenced results. Therefore, with respect to standardization and demands in daily life, a consistent test situation for all subjects was favored[20]. Except for sample size, there were no baseline (anthropometric) differences between groups. The added matched group analysis (BPP *vs* $H_{matched}$) did not change results of trunk EMG pattern analysis.

Conclusion

Neuromuscular trunk compensation strategies during one-handed lifting of different loads did not differ between H and BPP. Heavier loads led to an increase in trunk muscle activity (2- to 3-fold) with comparable patterns between groups. In both groups, the greatest activity was found in the contralateral abdominal muscles (VR). Heavy loading (20 kg) led to task failure, especially in women with back pain, implying reduced performance for these subjects. Consequently, the application of additional diagnostics are recommended, *e.g.*, strength assessment. Moreover, rehabilitation and prevention of back pain should focus on the preparation and compensation of high loading.

ACKNOWLEDGMENTS

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COMMENTS

Background

Back pain places a large burden on the healthcare systems of western industrialized nations. Research to develop approaches for the prevention of back pain could have a very beneficial effect. Therefore, the investigation of differences in trunk function between people with and without back pain is of primary interest in order to define adequate therapy and prevention strategies.

Research frontiers

An altered neuromuscular activity of the trunk muscles in back pain patients (BPP) is evident: Longer response times, altered recruiting patterns, extended activation times and increased co-contractions. Besides, these differences are only valid in situations where the load is applied suddenly either directly to the trunk or to the limbs. These situations are often limited in representing daily life activities which is highly comprised of lifting tasks. Since lifting tasks are omnipresent in daily life and correspond with an automated movement pattern, they seem expedient for the comparison of trunk muscle activity pattern between H and BPP. In terms of lifting tasks, one-handed carrying led to greater low back loads compared to two-handed carrying of the same weight due to an increased shear stress on the spine. Therefore, one-handed lifting proposes a more challenging situation compared to two-handed lifting.

Innovation and breakthroughs

This study demonstrates that BPP do not show an altered neuromuscular activity pattern, in terms of EMG amplitude, of the trunk during one-handed lifting of three different loads compared to healthy controls. Nevertheless, a significantly greater rate of task failure, while lifting heavy loads (20 kg), could be shown in BPP.

Applications

Neuromuscular trunk compensation strategies during one-handed lifting of different loads did not differ between healthy controls and BPP. Heavier loads led to an increase in trunk muscle activity (2- to 3-fold) with comparable patterns between groups. In both groups, the greatest activity was found in the contralateral abdominal muscles (VR). Heavy loading (20 kg) led to task failure, especially in women with back pain, implying reduced performance for these subjects. Consequently, the application of additional diagnostics are recommended, *e.g.*, strength assessment. Moreover, rehabilitation and prevention of back pain should focus on the preparation and compensation of high loading.

Peer-review

The authors investigated EMG of back muscles of people with or without back pain when they underwent one handed lift task. The methods were clear, and the results were easy to imagine and understand.

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