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 Hmatched) to the 7 BPP. In addition, task failure was calculated and compared between H/Hmatched vs BPP using $\chi^2$.

**RESULTS**

Seven subjects (3m/4f; 32 ± 7 years; 171 ± 7 cm; 65 ± 11 kg) were assigned to BPP (pain grade $\geq 2$) and 36 (13m/23f; 28 ± 8 years; 174 ± 10 cm; 71 ± 12 kg) to H (pain grade $\leq 1$). 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). $\chi^2$ 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

© The Author(s) 2017. Published by Baishideng Publishing Group Inc. All rights reserved.

Core tip: The aim of this study was to analyze neuromuscular 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.

Mueller J, Engel T, Kopinski S, Mayer F, Mueller S. Neuromuscular trunk activation patterns in back pain patients during one-handed lifting. *World J Orthop* 2017; 8(2): 142-148 Available from: URL: http://www.wjgnet.com/2218-5836/full/v8/i2/142.htm DOI: http://dx.doi.org/10.5312/wjo.v8.i2.142

**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$^{[7,8,11,12]}$, extended activation times$^{[7]}$ and increased co-contractions$^{[10,11]}$ have been described in affected patients$^{[12]}$. 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 decreased trunk muscle 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)
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 Hmatched) 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) 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 (Hmatched) vs BPP using χ². 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
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. $\chi^2$ analysis revealed significant differences 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 neuro-muscular activity patterns of the trunk in healthy con-
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 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.

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

The authors thank Michael Rector for assistance with proof reading of the manuscript.

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 contratralateral 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.

REFERENCES

1. Balagüé F, Mannion AF, Pellisé F, Cedraschi C. Non-specific low back pain. Lancet 2012; 379: 482-491 [PMID: 21982256 DOI: 10.1016/S0140-6736(11)60610-7]
2. Choi BK, Verbeek JH, Tam WW, Jiang JY. Exercises for prevention of recurrences of low-back pain. Occup Environ Med 2010; 67: 795-796 [PMID: 20959397 DOI: 10.1002/14651858.CD006555.pub2]
3. Mannion AF, Caporaso F, Pulkovski N, Sprott H. Spine stabilisation exercises in the treatment of chronic low back pain: a good clinical outcome is not associated with improved abdominal muscle function. Eur Spine J 2012; 21: 1301-1310 [PMID: 22270245 DOI: 10.1007/s00586-012-1915-9]
4. Bono CM. Low-back pain in athletes. J Bone Joint Surg Am 2004; 86-A: 382-396 [PMID: 14960688 DOI: 10.2106/00004623-20040200-0-00027]
5. Trainer TJ, Trainer MA. Etiology of low back pain in athletes. Curr Sports Med Rep 2004; 3: 41-46 [PMID: 14728913 DOI: 10.1249/014.9619-200402000-00008]
6. Cholewicki J, Simons AP, Radebold A. Effects of external trunk loads on lumbar spine stability. J Biomech 2000; 33: 1377-1385 [PMID: 10940396 DOI: 10.1016/S0021-9290(00)00118-4]
7. Ferguson SA, Marras WS, Burr DL, Davis KG, Gupta P. Differences in motor recruitment and resulting kinematics between back pain patients and asymptomatic participants during lifting exertions. Clin Biomech (Bristol, Avon) 2004; 19: 992-999 [PMID: 15531048 DOI: 10.1016/j.clinbiomech.2004.08.007]
8. Hanada EY, Johnson N, Hubley-Kozey C. A comparison of trunk muscle activation amplitudes during gait in older adults with and without chronic low back pain. PM R 2011; 3: 920-928 [PMID: 22024323 DOI: 10.1016/j.pmrj.2011.06.002]
9. Hodges PW, Moseley GL. Pain and motor control of the lumbopelvic region: effect and possible mechanisms. J Electromyogr Kinesiol 2003; 13: 361-370 [PMID: 12832166 DOI: 10.1016/S1050-6411(03)00042-7]
10. Nelson-Wong E, Callaghan JP. Is muscle co-activation a predisposing factor for low back pain development during standing? A multifactorial approach for early identification of at-risk individuals. J Electromyogr Kinesiol 2010; 20: 256-263 [PMID: 19467607 DOI: 10.1016/j.jelekin.2009.04.009]
11. Nelson-Wong E, Alex B, Cspe E, Lancaster D, Callaghan JP. Altered muscle recruitment during extension from trunk flexion in low back pain developers. Clin Biomech (Bristol, Avon) 2012; 27: 994-998 [PMID: 22877831 DOI: 10.1016/j.clinbiomech.2012.07.007]
12. Radebold A, Cholewicki J, Panjabi MM, Patel TC. Muscle response pattern to sudden trunk loading in healthy individuals and in patients with chronic low back pain. Spine (Phila Pa 1976) 2000; 25: 947-954 [PMID: 10767807 DOI: 10.1097/00007632-200004150-00009]
13. Maaswinkel E, Griffioen M, Perez RS, van Dieën JH. Methods for assessment of trunk stabilization, a systematic review. J Electromyogr Kinesiol 2016; 26: 18-35 [PMID: 26805526 DOI: 10.1016/j.jelekin.2015.12.010]
14. McGill SM, Marshall L, Andersen J. Low back loads while walking and carrying: comparing the load carried in one hand or in both hands. Ergonomics 2013; 56: 293-302 [PMID: 23384188 DOI: 10.1080/00140139.2012.752528]
15. Klase BM, Hallner D, Schaub C, Willburger R, Hasenbring M. Validation and reliability of the German version of the Chronic Pain Grade questionnaire in primary care back pain patients. Psychosoc Med 2004; 1: Doc07 [PMID: 19742049]
16. Radebold A, Cholewicki J, Polzhofer GK, Greene HS. Impaired postural control of the lumbar spine is associated with delayed muscle response times in patients with chronic idiopathic low back pain. Spine (Phila Pa 1976) 2001; 26: 724-730 [PMID: 11295888 DOI: 10.1097/00007632-200104010-00004]
17. Müller J, Müller S, Engel T, Reschke A, Baur H, Mayer F. Stumbling reactions during perturbed walking: Neuromuscular reflex activity and 3-D kinematics of the trunk - A pilot study. J Biomech 2016; 49: 933-938 [PMID: 26518368 DOI: 10.1016/j.jbiomech.2015.09.041]
18. Müller S, Stoll J, Müller J, Mayer F. Validity of isokinetic trunk measurements with respect to healthy adults, athletes and low back pain patients. Isokinet Exerc Sci 2012; 20: 255-266 [DOI: 10.3233/ IES-2012-00482]
19. Schneider S, Linspögl S, Schilitzenweig M. Occupations associated with a high risk of self-reported back pain: representative outcomes of a back pain prevalence study in the Federal Republic of Germany. Eur Spine J 2006; 15: 821-833 [PMID: 16432750 DOI: 10.1007/s00586-005-1015-2]
Mueller J et al. Trunk muscle activity in back pain patients during lifting
