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Fear avoidance beliefs are associated with reduced lumbar spine flexion during object lifting in pain-free adults

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Abstract

There is a long-held belief that physical activities such as lifting with a flexed spine is generally harmful for the back and can cause low back pain (LBP), potentially reinforcing fear avoidance beliefs underlying pain-related fear. In chronic LBP patients, pain-related fear has been shown to be associated with reduced lumbar range of motion during lifting, suggesting a protective response to pain. However, despite short term beneficial effects for tissue health, recent evidence suggests that maintaining a protective trunk movement strategy may also pose a risk for (persistent) LBP due to possible pro-nociceptive consequences of altered spinal motion, potentially leading to increased loading on lumbar tissues. Yet, it is unknown if similar protective movement strategies already exist in pain-free individuals which would yield potential insights into the role of fear avoidance beliefs in motor behavior in the absence of pain. Therefore, the aim of this study is to test whether fear avoidance beliefs influence spinal motion during lifting in a healthy cohort of pain-free adults without a history of chronic pain. The study subjects (N=57) filled out several pain-related fear questionnaires and were asked to perform a lifting task (5kg-box). High-resolution spinal kinematics were assessed using an optical motion capturing system. Time-sensitive analyses were performed based on statistical parametric mapping. The results demonstrated time-specific and negative relationships between self-report measures of pain-related fear and lumbar spine flexion angles during lifting, indicating potential

unfavorable interactions between psychological factors and spinal motion during lifting in pain-free subjects.

Keywords: pain-related fear; spine kinematics; flexion; Low Back Pain; fear avoidance beliefs; range of motion; lifting; statistical parametric mapping

1. Introduction

Emotions and beliefs shape how humans move and vice versa [28,40]. A prime example for this interplay is pain: people move differently in (the expectation of) pain, and conversely, dysfunctional or degraded movement can enhance pain [11,23,32]. This particularly applies to body parts thought to require superior protection such as the back [12,13,22]. Common beliefs are that the back is easily injured and that the healing process is long [12]. Such beliefs can increase protective behaviors, including control of posture and avoidance of daily activities, potentially aggravating disability and pain in the long term [13,32,64,68].

Activities that are believed by many to be harmful for the back, and even a potential cause of low back pain (LBP), include lifting with a flexed spine [8,19,55]. However, recent studies have not found convincing evidence that the spine should not be flexed during lifting to prevent LBP [14,31,55,65,67,69]. On the contrary, maintaining a protective strategy, e.g. by keeping a neutral spine (i.e. not flexing the spine) during lifting, has been shown to be associated with rigid motor behavior, increased muscle co-contraction and mechanical loading on spinal tissues [10,18,21]. In the long term, this can provoke pro-nociceptive mechanisms, potentially initiated by deterioration of (para)spinal tissues and decreased movement (variability) [5,21,32,34,64]. Yet, many health care professionals still promote lifting with a neutral spine as the safer lifting technique [44,55,67], potentially reinforcing erroneous fear avoidance beliefs (i.e. flexed back danger beliefs) underlying pain-related fear. In support of this notion, recent evidence indicates an implicit bias towards "lifting with a flexed spine is dangerous", compared to lifting with a neutral spine, in patients with persistent LBP as well as in pain-free individuals [7,8]. Brain research further supports this by demonstrating distinct relationships between self-reports of pain-related fear and fear-related neural activity during observation of daily activities such as lifting with a flexed spine in LBP and pain-free subjects [37,38,62]. However, the underlying interactions between pain-related fear and spinal motion are largely unknown and need to be elucidated to disentangle possible clinically relevant relationships between pain-related fear, spinal motion, and negative outcomes such as persistent LBP and disability. With respect to this, there is a lack of studies measuring lumbar spine flexion during lifting mimicking real life settings [55], especially with regards to psychological factors in people with and without LBP. First insights came from a cross-sectional study demonstrating that flexed back danger beliefs are associated with a protective strategy in chronic non-specific LBP patients, characterized by a reduced sagittal plane lumbar range of motion (ROM) during a lifting task [36]. However, based on the reportedly pre-existing fear avoidance beliefs in pain-free individuals [7,38], it would be crucial to know whether these beliefs are also associated with spinal motion in pain-free subjects, yielding potential insights into the role of fear avoidance beliefs in motor behavior in the absence of pain.

Therefore, using high-resolution spinal kinematics, we investigated whether fear avoidance beliefs are associated with lumbar motion during lifting in pain-free adults. In addition to conventional ROM analyses, we applied statistical parametric mapping to obtain time-sensitive information regarding changes of spinal motion [45].

2. Methods

2.1. Participants

Sixty-one pain-free and healthy adults (males/females: 31/30; age: 29.5 ± 6.9 years) were enrolled in this study. Recruitment took place between January and November 2019, using the following inclusion criteria: age between 18-60 years, no acute or recurrent LBP within the past 3 months, no history of chronic pain, no prior spine surgery, no history of psychiatric or neurological disorders, not being pregnant, no consumption of alcohol or drugs within the past 24 hours and a BMI of lower or equal to 30 kg/m^2. The study protocol was approved by the local ethics committee (Kantonale Ethikkommission Zürich, EK-01/2019/PB_2018_01001) and conformed to the Declaration of Helsinki. All participants provided written informed consent prior to any study-related activities. They were invited for a single visit at the local university hospital, where they completed several questionnaires and underwent a three-dimensional optical full-body movement analysis.

2.2. Questionnaires

Participants completed the two following questionnaires assessing pain-related fear:

1) The modified 17-item German version of the Tampa Scale for Kinesiophobia (TSK) for the general population (TSK-G) assesses subjective ratings of pain-related fear of

movement/(re)injury due to physical activity and kinesiophobia using a 4-point Likert scale ranging from 1 = “strongly disagree” to 4 = “strongly agree” [24]. It includes questions such as “If I had pain, I would feel better if I was physically active” and therefore measures more general aspects of pain-related fear. Psychometric research indicated a sufficient reliability (Cronbach’s α = 0.78); the score range lies between 17 (low level of kinesiophobia) and 68 (high level of kinesiophobia) [24].

2) The Photograph Series of Daily Activities - Short electronic Version (PHODA-SeV) is a tool for measuring the perceived harmfulness of certain movements. Pictures of different daily tasks are presented to the participants who are then asked to imagine themselves in the shown situations and indicate how harmful they think these activities would be to their back on a scale from 0 to 100 (0 = not harmful at all; 100 = extremely harmful, reflecting beliefs underlying *activity-specific* pain-related fear). The internal consistency of the total score on the PHODA-SeV, as indicated by Cronbach’s α, was reported as 0.98 and the corrected item-total correlations ranged between 0.42 and 0.82, indicating that each item was moderately to highly related to the other items [46]. For the current study, we chose a priori the overall score (PHODA-total, overall score of all PHODA items which is considered a more *general* measure of pain-related fear [36]) and the score of the item showing a person lifting a flowerpot with a bent back (PHODA-lift) as variates of interest. Lifting a flowerpot best reflects a typical lifting task and has demonstrated a specific relationship between harmfulness ratings and the lumbar lifting ROM in chronic LBP patients [36].

To investigate potential differences or shared variance between self-reports of pain-related fear and general anxiety, we used the State-Trait Anxiety Inventory (STAI), which includes two subscales [59]. The State Anxiety Scale (S-Anxiety) assesses current levels of anxiety, whereas the Trait Anxiety Scale (T-Anxiety) evaluates more stable aspects of anxiety such as "anxiety proneness" [29].

2.3. Full-body movement analysis

Participants were equipped with 58 retro-reflective skin markers placed by a physiotherapist or movement scientist with experience in palpation according to a previously described marker configuration [56]. To enable detailed tracking of spinal motion, this configuration included markers placed on the spinous processes of C7, T3, T5, T7, T9, T11, L1 to L5 and S1 (Figure 1).

Participants were then asked to perform a series of activities of daily-living including upright standing and sitting on a chair, bending forward and backward from an upright standing position without bending their knees, standing up from a chair and sitting down on a chair with free hanging arms, lifting-up and putting-down a 5 kg-box (40 × 30 × 17 cm) that was placed 15 cm in front of the subjects' feet, walking and running on a level ground as well as climbing up and down a stair with four steps. No further instructions were given to ensure individual and natural movements at self-selected speeds. Apart from standing, sitting and bending (performed once), all activities were repeated until five valid trials were collected. For familiarization with the tasks the participants practiced the activities prior to the actual testing. Testing was repeated if the participants violated the task instructions, resulting in non-valid trials. For the current study only data from bending and lifting activities were considered.

Three-dimensional marker positions were tracked using a 20-camera optical motion capturing system (Vicon UK, Oxford, UK) at a sampling frequency of 200 Hz.

2.4. Data reduction and outcome parameters

Motion capture data were pre-processed using the software Nexus (version 2.8.1, Vicon UK, Oxford, UK), involving marker reconstruction and labeling, gap filling and filtering of the marker trajectories as well as setting of temporal events for the identification of the relevant data sections.

Post-processing was carried out with a custom-built MATLAB routine (R2019a, MathWorks Inc., Natrick, MA, USA). In a first step, marker data were cropped according to the temporal events set during pre-processing or defined using a previously described event-detection algorithm (i.e. end point of the lifting-up as well as starting point of the putting-down activities) [61].

Lumbar angles of the bending forward activity as well as lumbar and thoracic angles of the lifting activity were calculated based on the trajectories of the L1 to S1 and C7 to T11 markers, respectively, using a combination of a quadratic polynomial and a circle fit function [57]. For the lifting activity, we additionally applied a quintic polynomial function to all sagittal plane spinal marker trajectories (i.e. C7 to S1) to derive regional lumbar angles (angles between the normal lines passing through the L1, L2, L3, L4, L5 and S1 skin markers [25,26]). Vertical marker placement accuracy was previously shown to be within 5-18 mm for the thoracic and 7-14 mm for the lumbar region, with a tendency of placing the markers slightly lower than the designated locations [57]. Soft tissue artifacts in a flexed compared to an extended position were shown to be within 9-11 mm for the thoracic and lumbar regions [71]. For time-sensitive analyses, continuous angles from the lifting activity were time-normalized on 101 points (time window: 0 – 100%) and averaged across all five trials (per subject). To obtain ROM values for the analyzed tasks, continuous angles were reduced to a discrete flexion ROM value (averaged across the five trials), i.e. angle difference between upright standing and maximal deviation from the starting position. All angles were expressed in degrees (°).

The continuous lumbar lordosis angles in the sagittal plane during lifting-up and putting-down a box were the primary outcomes. Secondary outcomes included the continuous thoracic kyphosis angles and the lumbar regional angles in the sagittal plane during lifting-up and putting-down a box.

2.5. Statistical analysis

Statistical calculations were performed using SPSS (version 23, SPSS Inc., Chicago, IL, USA) and the Python-based software package for one-dimensional Statistical Parametric Mapping (SPM: spm1d-package, www.spm1d.org) [46]. SPM was originally developed for analyzing voxel time-series related to brain function [3] but can also be used to analyze time-series of kinematic data, which offers several advantages over conventional ROM analysis [46,48]. One major advantage of SPM is the ability to analyze time-sensitive information of an entire movement cycle rather than simple discrete (peak) values provided by ROM analysis [45,48]. Prior to any inferential analyses, data were tested for normality using the D'Agostino's K2 test (SPM function *spm1d.stats.normality.k2.ttest*) for the continuous spinal angles and the Shapiro-Wilk test and Q-Q plot inspection for measures of pain-related fear. In case of non-normal distribution of the questionnaire data, Spearman's rank correlation coefficient was used for correlation analysis. To investigate potential relationships between continuous spinal angles and measures of pain-related fear, we conducted multiple linear regression analyses (SPM function *spm1d.stats.glm*) using measures of pain-related fear as regressors of interest and age, gender and bending ROM as nuisance variables (as they have been shown to possibly influence lumbar and thoracic curvature angles [2,27,35]). For each measure of pain-related fear, a separate regression analysis for the lifting-up and putting-down phases was performed and the output statistic SPM{t} was calculated at each of the 101 time points.

Tests were based on the null hypothesis, i.e. there are no relationships between continuous spinal angles and the respective measure of pain-related fear. Assuming principles of Random Field Theory that were validated for 1D data [47,49], statistical significance was determined by a critical SPM{t}-threshold at which only α% (5%) of smooth random curves would be expected to traverse [45]. This leads to "supra-threshold clusters" that characterize significant time-specific positive or negative relationships between spinal angles and measures of pain-related fear. For a better interpretability of the effect sizes, the respective t-statistics were transformed to correlation coefficients (r) based on the following formula:

$$t = r * \sqrt{\frac{n-2}{1-r^2}}$$

Multiple comparisons correction was performed for primary outcomes and was based on a false discovery rate (FDR) of 5% [4] (including six separate tests for TSK-G, PHODA-total, PHODA-lift regressors and continuous lumbar lordosis angles in lifting-up and putting-down phases).

To compare the actual data in pain-free adults with ROM analyses recently performed in chronic LBP patients [36], we conducted correlation analyses between the lumbar ROM during lifting and measures of pain-related fear (TSK-G and each PHODA item, section 3.7) using the same regression model and nuisance variables described above.

Furthermore, multiple regression analyses were performed including the TSK-G score (as a measure of general pain-related fear) as nuisance variable (in addition to age, gender and bending ROM) to test if activity-specific pain-related fear (PHODA items) explains additional variance in spinal motion during lifting after accounting for linear effects of the TSK-G score (section 3.6)

3. Results

3.1. Recruitment and subject characteristics

Four subjects had to be excluded from the analysis, resulting in a final sample of 57 pain-free healthy adults (males/females: 30/27; age: 29.5 ± 7.0 years; mass: 67.9 ± 11.8 kg; height: 174.4 ± 8.9 cm; BMI: 22.2 ± 2.6 kg/m^2). The reasons for the exclusions were technical issues that led to the loss of the kinematic data (1 subject), conceptual misunderstanding of the PHODA questionnaire (1 subject, stating having switched the endpoints of the scale) and a hyperlordosis of the lumbar spine in neutral position with an angle of > 68° [15,30] (2 subjects).

3.2. Questionnaire data

The analysis of the PHODA harmfulness ratings indicated similar threat values for the a priori chosen item PHODA-lift and the items “shoveling soil” (PHODA-shoveling) and “falling backwards” (PHODA-falling) (see Table 1). We therefore added the latter two items post-hoc in the correlation analysis and performed exploratory time-sensitive regression analyses (see section 3.5).

Q-Q plots inspection and the Shapiro-Wilk test indicated non-normality for the PHODA-lift ($p = 0.019$) and PHODA-shoveling ($p = 0.022$) as well as for the T-Anxiety ($p = 0.002$) and S-Anxiety ($p = 0.001$) score distributions. The PHODA-total, PHODA-falling and TSK-G scores were normally distributed ($p > 0.05$). Mean scores were 31.8 (SD=±5.5) for the TSK-G, 37.5 (SD=±6.5) for the T-Anxiety and 30.4 (SD=±7.5) for S-Anxiety. Mean values for each PHODA item are listed in Table 1. The T-Anxiety score moderately correlated with the PHODA-falling (Spearman's $r = 0.244$, $p = 0.034$) and TSK-G ($r = 0.233$, $p = 0.040$) scores. No significant correlations were found between the TSK-G and PHODA-total, PHODA-lift, PHODA-shoveling and PHODA-falling scores (r's < 0.16, p's > 0.13). Significant correlations were found between the different PHODA items (PHODA-lift, PHODA-shoveling and PHODA-falling, r's > 0.37, p's < 0.02), indicating that they share some variance. The results of the correlation analyses are summarized in Table 2.

3.3. Relationships between TSK-G, PHODA-lift, PHODA-total and continuous lumbar and thoracic angles during lifting

Multiple linear regression analysis revealed a statistically significant negative relationship between the PHODA-lift score and continuous lumbar angles during the lifting-up (time window: 9-92%, $-0.313 \leq r \geq -0.310$, $p_{FDR} = 0.007$) and putting-down (time window: 17-60%, $-0.315 \leq r \geq -0.306$, $p_{FDR} = 0.028$) phases (Figure 2A and 2B, Table 3), indicating an association between flexed back danger beliefs and lumbar kinematics during lifting. No relationships were found for TSK-G, PHODA-total and continuous lumbar angles nor for any of the three scores and continuous thoracic angles ($p_{FDR} > 0.05$).

3.4. Relationships between PHODA-lift and continuous lumbar regional angles during lifting

Multiple regression analyses with the continuous lumbar regional angles as dependent variables revealed that the time-specific relationships between the lumbar lordosis angle and the PHODA-lift score were most likely driven by motion in the lower lumbar region, indicated by time-specific relationships between the PHODA-lift score and the relative angle of the normal lines passing through the L4 and L5 skin markers during the lifting-up (time window: 0-61%, $-0.333 \leq r \geq -0.315$, $p_{uncorr} = 0.021$) as well as the putting-down (time window: 29-100%, $0.354 \leq r \geq -0.305$, $p_{uncorr} = 0.012$) phases (Figure 3A and 3B, Table 4).

3.5. Relationships between PHODA-falling, PHODA-shoveling and continuous lumbar and thoracic angles during lifting

Using the PHODA-falling score as regressor of interest, a significant negative relationship to continuous lumbar angles was found during the lifting-up (time window: 0-77%, $-0.484 < r > -0.319$, $p_{FDR} = 0.010$) and putting-down phases (time window: 16-100%, $-0.466 < r > -0.302$, $p_{FDR} = 0.005$) (Figure 4A and 4B). Furthermore, the PHODA-falling score showed a significant negative relationship to the motion in almost all lumbar regions during both lifting phases (see Table 4). No significant relationships were found between thoracic angles and the PHODA-falling score, nor between the PHODA-shoveling score and continuous lumbar and thoracic angles ($p_{FDR} > 0.05$, see Table 3).

3.6. Effects of activity-specific pain-related fear on continuous lumbar angles after accounting for linear effects of the TSK-G score

When including the TSK-G score as nuisance variable in the regression model, the observed negative relationships between the PHODA-lift score and the continuous lumbar angles remained statistically significant for both lifting phases (lifting-up: time window: 9-89%, $-0.310 < r > -0.307$, $p_{uncorr} = 0.008$; putting-down: time window: 15-60%, $-0.315 < r > -0.305$, $p_{uncorr} = 0.027$).

Similarly, the negative relationships between the PHODA-falling score and the continuous lumbar angles remained statistically significant for both lifting phases (lifting-up: time window: 0-76%, $-0.491 < r > -0.317$, $p_{uncorr} = 0.010$; putting-down: time window: 15-100%, $-0.472 < r > -0.306$, $p_{uncorr} = 0.005$).

3.7. Relationships between lumbar ROM during lifting and measures of pain-related fear

The lumbar ROM during lifting did not show a relationship with the TSK-G score ($r = -0.006$, $p = 0.965$). Regarding the PHODA items, only the PHODA-falling score showed a statistically significant correlation with the lumbar ROM ($r = -0.380$, $p = 0.004$). The results from the correlation analysis between the lumbar ROM during lifting and the different PHODA items are found in Table 1.

4. Discussion

This study investigated whether fear avoidance beliefs are associated with lumbar motion in pain-free subjects to obtain information on potential interactions between psychological factors and spinal motion in the absence of pain. To this end, we performed analyses of continuous (SPM) and discrete (ROM) sagittal plane spinal kinematics during a load lifting task, which is often perceived as a dangerous activity for the back [7,8,12] and correlated these data with self-reports of pain-related fear and beliefs commonly used in research and clinical practice to assess different types of pain-related fear (general and activity-specific). The results demonstrated a time-specific association between pain-related fear and lumbar motion during a lifting maneuver in pain-free subjects.

The association of pain-related fear with spinal motion in pain-free adults

Current findings support the evolving evidence that fear avoidance beliefs underlying pain-related fear exist in the pain-free population [7,33,38]. Furthermore, the results indicate different sensitivities of pain-related fear measures in explaining variance of lumbar motion during lifting. No effects of pain-related fear on thoracic motion were observed. General measures of pain-related fear, such as the TSK-G or the average PHODA score (PHODA-total), did not show an association with lumbar motion during lifting. In contrast, activity-specific pain-related fear, reflected by subjective ratings of potentially harmful movements during daily activities (PHODA-lift, PHODA-falling), demonstrated time-specific relationships with lumbar motion during lifting, even after accounting for linear effects of the TSK-G. This partially agrees with a recently reported association of pain-related fear with lumbar ROM during lifting in chronic LBP patients [36]. In line with the current study, Matheve et al. [36] observed a significant negative relationship between flexed back danger beliefs (PHODA-lift) and lumbar motion during a lifting task, supporting the construct validity of the PHODA-lift item. However, we only observed the above-mentioned relationship in the time-sensitive SPM analysis, but not in the ROM analysis (which is contradictory to the study of Matheve et al. [36] reporting a significant association between the PHODA-lift score and the lumbar ROM during lifting). Differences between ROM and SPM outcomes have been also reported in other studies [45,52,58] and may occur due to the different underlying analysis domains (peak values in ROM analysis versus the entire time movement cycle in the SPM analysis) [58]. The discrepancy between SPM outcomes and ROM in our results might be explained by a more subtle association between the PHODA-lift score and lumbar spinal motion in pain-free individuals compared to chronic LBP patients, emphasizing the added value of time-sensitive analyses [45]. However, further comparisons of continuous (SPM) versus discrete analysis (ROM) regarding spinal motion and psychological factors are needed to better understand and interpret potential differences of both analysis approaches.

In the current study, only the PHODA item showing a person falling backwards on the grass demonstrated a significant association with the lumbar ROM during lifting. Such a relationship was not observed in chronic LBP patients [36]. The SPM analysis yielded a significant association between the PHODA-falling score and lumbar spine angles in both lifting phases. This indicates that other PHODA-items (i.e. PHODA-falling) which are not directly related to the lifting task can demonstrate an association with lumbar kinematics during lifting, at least in healthy pain-free individuals. At this stage we can only speculate about potential reasons for this finding. The items PHODA-falling and PHODA-lift showed some shared variance (see table 2) while having differential effects on the SPM outcomes. The PHODA-lift score was significantly associated with motion of the lower lumbar region (indicated by the angle between the normal lines passing through the L4 and L5 skin markers). In contrast, the SPM analysis of the PHODA-falling item yielded a broad and lumbar region-spanning association with lumbar spine angles (see table 4), suggesting non-specific effects (regarding the illustrated activity) on lumbar regional motion during lifting. With respect to this, the PHODA-falling item was the only item that correlated with trait anxiety, indicating that this item might share some variance with more general anxiety-related beliefs that might affect motor behavior [51].

A protective movement strategy with potential negative consequences?

Based on the use of continuous analysis with a novel methodology (SPM), the current results suggest that pain-related fear is associated with less lumbar flexion during lifting in pain-free individuals which may indicate a protective movement strategy as it has been suggested in chronic LBP patients [36]. According to the SPM analysis, this potential protective behavior seems to occur during distinct time windows of the lifting-up and putting-down phases. The reduced lumbar flexion during lifting is likely achieved through altered neuromuscular activation/coordination, consistent with reports describing a protective response (i.e. tight control strategy), characterized by stiffening lumbar segments through antagonistic muscle activation [9,17,41,53,54,70]. In LBP patients, such a protective strategy has been suggested as being beneficial in the short term by avoiding further pain or injury [41,64]. In the long-term, however, maintaining a protective strategy has been linked with pro-nociceptive mechanisms for LBP persistence through reduced movement, rigid motor behavior and associated guarding with increased paraspinal muscle activation that may lead to increased spinal loading

[22,39,41,54,64,66]. Increased spinal loading is known for initiating or accelerating spinal tissue degeneration [34,50,63]. Furthermore, an electromyographic study showed that pain-related fear is related to altered paraspinal muscle activity and restricted flexion in chronic LBP patients [16], indicating possible clinically relevant interactions between pain-related fear, lumbar flexion and paraspinal muscle activity. These interactions and their potential contribution to LBP persistence are gaining increasing attention [23,66]. In contrast, evidence about movement strategies in pain-free subjects and their potential role in a future LBP episode is sparse. Protective responses have been observed in pain-free individuals during anticipation of experimental back pain, characterized by reduced activation of deep trunk muscles and increased activation of superficial trunk muscles [41], similar to observations in patients with recurrent LBP [20]. This behavior in pain-free subjects has been hypothesized to be linked with spinal injury if maintained long-term [41]. However, while the current results suggest an association between pain-related fear and spinal motion in pain-free subjects, they do not allow to draw conclusions about a relationship between motor behavior in a pain-free state and motor behavior in a future LBP episode. In this respect, there is a need for more (cross-disciplinary) research including longitudinal designs to disentangle possible causal relationships between lumbar flexion in daily activities, muscle activation patterns, spinal loading, and the development and/or persistence of LBP.

Pre-existing beliefs about lifting

Flexed back danger beliefs, often held and communicated by health care professionals and manual handling advisors [44], likely originate from earlier *in vitro* studies investigating the effects of loads on cadaveric spines [1,6] and *in vivo* studies measuring intradiscal pressure [42,43], which led to the conclusion that lifting weights with a flexed spine yields a higher risk for disk injuries and LBP, compared to lifting with a neutral spine [42,43]. However, more recent studies do not support this notion. Dreischarf and colleagues (2016) reported only a 4% difference in load between the two different lifting techniques using an instrumented vertebral body replacement [14]. Lifting heavy loads under certain conditions (e.g. being distracted or fatigued) might indeed pose strong risks for triggering an acute LBP episode [60] and specific lifting techniques might be essential in certain work-related and everyday life situations. Nonetheless, we argue that the importance of lifting with a neutral spine in everyday activities has been greatly exaggerated. In support of this, recent systematic review concluded that the current advice to avoid lumbar flexion during lifting to prevent LBP is not justified [55].

Limitations

There are some limitations of the current study that need to be mentioned. The measurement of spine angles using skin markers is strictly speaking a measurement of the external shape of the back in the thoracolumbar region rather than an actual measurement of the angles between the respective vertebral bodies. Previous research showed that these angles differ by about 20° [71]. This limits the direct comparison with angles reported in other studies; however, it does not affect the results of our regression analyses since all participants were measured identically. Furthermore, the accuracy of predicted curvature angles might have been affected by accumulating soft tissue in more extended positions of the lumbar spine. However, previous research showed that such inaccuracies occur mainly in lumbar extensions of more than 40° [57] and because most of the lumbar lordosis angles during the important phases in the current study were below 40° of extension, we do not expect that the current findings were driven by soft tissue-related inaccuracies.

Conclusion

The results indicate that reduced lumbar flexion (which may be interpreted as a protective movement strategy) can be associated with beliefs about the harmfulness of daily activities such as lifting with a flexed spine, in the absence of (experimental) pain.

Furthermore, the current approach and results provide a promising basis for longitudinal study designs including kinematic and biomechanical measures to disentangle the interactions between psychological factors, (spinal) motor behavior and the development/persistence of LBP. The results also emphasize the need to raise more awareness of potential negative implications of erroneous beliefs regarding lifting techniques in the public and health sector.

Figure legends

Figure 1. A = Full body marker placement according to Schmid et al. [56] including head, pelvis, thorax, spine, shoulder, elbow, wrist, arms and lower extremities. Markers placed on the spinous processes of C7, T3, T5, T7, T9, T11, L1 to L5 and S1 were used for tracking of spinal motion. B = Vicon interface showing the captured and reconstructed 3D marker positions before (left) and after labeling and Plug-in Gait model calculations (right).

Figure 2. A = Individual (N = 57) continuous lumbar lordosis angle during lifting-up (left) and putting-down (right) phases. X-axis: time normalized on 101 points (time window: 0 – 100%). B = t-statistics with supra-threshold clusters reflecting significant time-specific negative relationships between the angle and the PHODA-lift (B) score, revealed by SPM1D multiple linear regression.

Figure 3. A = Individual (N = 57) continuous angle between the normal lines passing through the L4 and L5 skin markers during lifting-up (left) and putting-down (right) phases. X-axis: time

normalized on 101 points (time window: 0 – 100%). B = t-statistics with supra-threshold clusters reflecting significant time-specific negative relationships between the angle and the PHODA-lift (B) score, revealed by SPM1D multiple linear regression

Figure 4. A = Individual (N = 57) continuous lumbar lordosis angle during lifting-up (left) and putting-down (right) phases. X-axis: time normalized on 101 points (time window: 0 – 100%). B = t-statistics with supra-threshold clusters reflecting significant time-specific negative relationships between the angle and the PHODA-falling (B) score, revealed by SPM1D multiple linear regression.

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Table 1: Spearman's rank correlations (r) between scores on individual PHODA-SeV items and lumbar range of motion during lifting, sorted according to the mean threat value in descending order. Reported are mean ± SD and median with interquartile range (IQR).

ID	Description	Score on item		Lifting ROM	
		Mean (SD)	Median (IQR)	Correlation	p-value
1	Shoveling soil	51.3 (29.5)	50 (29-80)	-0.121	0.370
38	Falling backwards	49.5 (25.3)	53 (33-69)	-0.380	**0.004**
3	Lifting pot, bent back	47.5 (28.5)	50 (24-73)	-0.113	0.404
10	Lifting beer crate, bent back	31.7 (22.9)	30 (12-49)	-0.143	0.287
21	Taking box from shelf above head	30.2 (27.1)	24 (7-52)	-0.080	0.555
31	Lifting toddler	29.9 (20.8)	29 (11-47)	-0.124	0.357
11	Carrying bag, one hand	28.1 (21.6)	27 (11-44)	-0.055	0.684
40	Drilling hole above head	27.6 (20.7)	27 (10-41)	-0.008	0.953
32	Carrying child on hip	27.5 (20.1)	25 (12-43)	0.007	0.958
16	Vacuum cleaning	26.9 (23.4)	20 (7-42)	-0.124	0.358
13	Carrying rubbish, one hand	24.0 (20.2)	23 (6-35)	-0.013	0.925
4	Picking up, bent	22.4 (23.9)	13 (3-35)	-0.062	0.644
39	Mowing lawn	22.3 (18.3)	22 (3-36)	0.083	0.540
17	Mopping floor	18.6 (16.1)	15 (7-26)	-0.014	0.915
20	Back bending	18.2 (20.5)	10 (3-29)	0.162	0.229
22	Trampoline jumping	17.9 (19.7)	10 (3-30)	0.005	0.968
25	Making bed	17.5 (18.5)	11 (4-27)	-0.001	0.993
9	Lifting basket, stairs	17.4 (16.1)	12 (3-29)	0.043	0.750
29	Cleaning windows above head	16.7 (16.9)	11 (5-25)	-0.028	0.834
23	Rope skipping	16.1 (16.7)	11 (3-28)	0.037	0.786
19	Back twisting	15.8 (15.5)	12 (2-25)	0.223	0.095
34	Running	15.6 (15.0)	10 (3-29)	-0.001	0.995
12	Carrying bag, both hands	15.3 (13.1)	14 (5-24)	0.023	0.864
18	Leg stretching	15.3 (15.1)	11 (3-25)	0.084	0.533
24	Abdominal exercises	15.0 (17.1)	8 (3-23)	0.116	0.391
33	Doing dishes	13.5 (14.6)	8 (2-23)	0.087	0.522
7	Ironing, standing	13.2 (19.2)	5 (0-19)	0.100	0.461
14	Clear dishwasher	12.6 (13.5)	8 (3-20)	-0.059	0.665
37	Cycling, looking aside	12.5 (16.8)	7 (2-18)	-0.034	0.804
2	Lifting pot, squat	11.8 (10.8)	10 (0-20)	-0.111	0.413
36	Cycling from kerb	11.5 (16.1)	7 (1-15)	-0.011	0.938
15	Taking from cupboard	11.3 (14.1)	7 (0-16)	0.147	0.276
5	Picking up, squat	11.0 (15.4)	4 (0-17)	0.029	0.828
30	Riding bike, bumpy	10.9 (17.2)	6 (0-12)	0.063	0.641
6	Taking box, twisted back	10.9 (14.3)	5 (0-16)	0.096	0.477
26	Getting out of bed	8.8 (10.6)	4 (1-14)	0.126	0.350
8	Ironing, sitting	7.2 (9.7)	3 (0-11)	0.105	0.435
28	Walking down stairs	6.7 (9.4)	3 (0-7)	0.051	0.708
35	Walking	5.2 (7.5)	2 (0-10)	0.033	0.810
27	Walking up stairs	3.9 (6.2)	1 (0-5)	0.004	0.976
	Phoda-total	19.2 (12.2)	19.1 (8-28)	-0.027	0.845

Table 2. Spearman's rank correlations (r) between the different questionnaires and PHODA items. Tampa Scale of Kinesiophobia for the general population (TSK-G). State and Trait Anxiety Inventory (S-Anxiety. T-Anxiety). PHODA items: lifting a flowerpot (PHODA-lift), falling backwards on the grass (PHODA-falling), shoveling soil (PHODA-shoveling). $p<0.05$ (bold).

		S-Anxiety	*T-Anxiety*	*TSK-G*	*PHODA-lift*	*PHODA-falling*	*PHODA-shoveling*	*PHODA-total*
S-Anxiety	r	1.000	**.589**	**.303**	-.041	-.065	-.205	-.123
	p		**.000**	**.011**	.382	.315	.063	.180
T-Anxiety	r	**.589**	1.000	**.233**	.156	**.244**	-.130	-.031
	p	**.000**		**.040**	.123	**.034**	.463	.409
TSK-G	r	**.303**	**.233**	1.000	.161	.141	.089	.150
	p	**.011**	**.040**		.116	.148	.256	.133
PHODA-lift	r	-.041	.156	.161	1.000	**.456**	**.779**	**.805**
	p	.382	.123	.116		**.000**	**.000**	**.040**
PHODA-falling	r	-.065	**.244**	.141	**.456**	1.000	**.374**	**.554**
	p	.315	**.034**	.148	**.000**		**.002**	**.000**
PHODA-shoveling	r	-.205	-.130	.089	**.779**	**.374**	1.000	**.717**
	p	.063	.463	.256	**.0000**	**.002**		**.000**
PHODA-total	r	-.123	-.031	.150	**.805**	**.554**	**.717**	1.000
	p	.180	.409	.133	**.040**	**.000**	**.000**	

Table 3: Relationships between measures of pain-related fear and continuous lumbar and thoracic angles during lifting

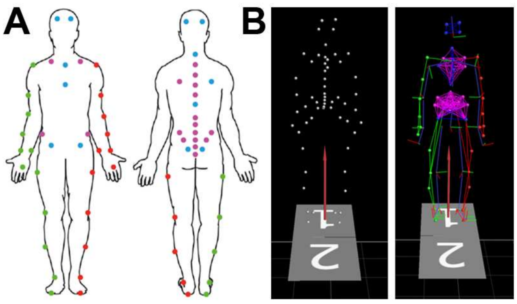
Lifting phase	Spinal region	Regressor	t-value	r-value	p-value
Lifting up	Lumbar (L1 – S1)	PHODA-lift	-2.455	-0.313 < r > -0.310	**0.007***
		PHODA-total	-2.446		0.107
		TSK-G	-2.439		0.819
		PHODA-shoveling	-2.439		0.707
		PHODA-falling	-2.452	-0.484 < r > -0.319	**0.010***
	Thoracic (C7 – T11)	PHODA-lift	-2.247		1.000
		PHODA-total	-2.245		1.000
		TSK-G	-2.245		0.901
		PHODA-shoveling	-2.247		0.345
		PHODA-falling	-2.247		0.871
Putting down	Lumbar (L1 – S1)	PHODA-lift	-2.470	-0.315 < r > -0.306	**0.028***
		PHODA-total	-2.465		0.063
		TSK-G	-2.456		0.994
		PHODA-shoveling	-2.457		0.669
		PHODA-falling	-2.471	-0.466 < r > -0.302	**0.005***
	Thoracic (C7 – T11)	PHODA-lift	-2.245		1.000
		PHODA-total	-2.245		1.000
		TSK-G	-2.240		0.913
		PHODA-shoveling	-2.247		0.261
		PHODA-falling	-2.247		0.897

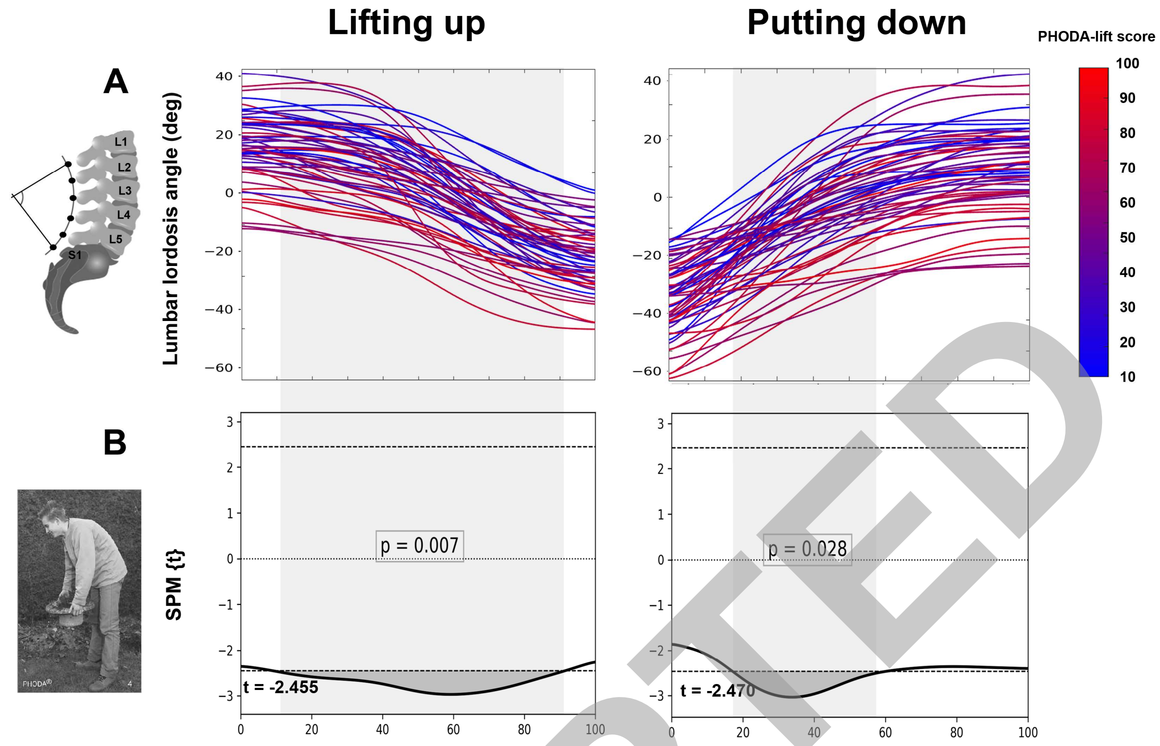
* $p < 0.05$, FDR-corrected (5%)

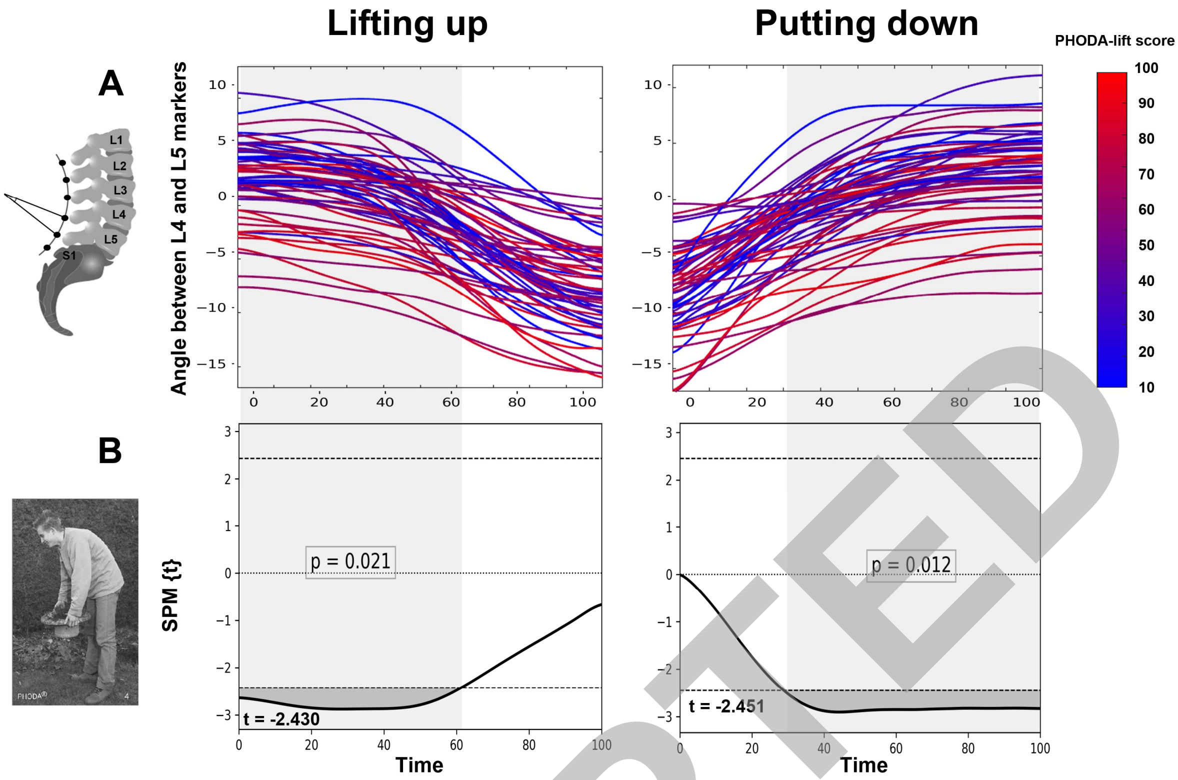
Table 4: Relationships between measures of pain-related fear and continuous regional lumbar angles during lifting (uncorrected p-values)

Lifting phase	Markers*	Regressor	t-value	r-value	p-value
Lifting up	T11 and L1	PHODA-lift	2.361		1.000
	L1 and L2		2.410		0.324
	L2 and L3		2.444		0.224
	L3 and L4		2.463		0.364
	L4 and L5		2.430	-0.333 < r > -0.315	**0.021**
	L5 and S1		2.451		0.281
	T11 and L1	PHODA-falling	2.355	-0.316 < r > -0.303	**0.040**
	L1 and L2		2.408	-0.342 < r > -0.312	**0.025**
	L2 and L3		2.442	-0.359 < r > -0.314	**0.016**
	L3 and L4		2.462	-0.424 < r > -0.318	**0.016**
	L4 and L5		2.434	-0.465 < r > -0.315	**0.017**
	L5 and S1		2.455	-0.334 < r > -0.316	**0.013**
Putting down	T11 and L1	PHODA-lift	2.381		0.644
	L1 and L2		2.417		0.702
	L2 and L3		2.459		0.657
	L3 and L4		2.485		0.591
	L4 and L5		2.451	-0.354 < r > -0.305	**0.012**
	L5 and S1		2.450		0.281
	T11 and L1	PHODA-falling	2.377		0.889
	L1 and L2		2.416		0.706
	L2 and L3		2.460	-0.316 < r > -0.306	**0.014**
	L3 and L4		2.486	-0.400 < r > 0.309	**0.008**
	L4 and L5		2.459	-0.475 < r > -0.299	**0.009**
	L5 and S1		2.457	-0.340 < r > -0.301	**0.007**

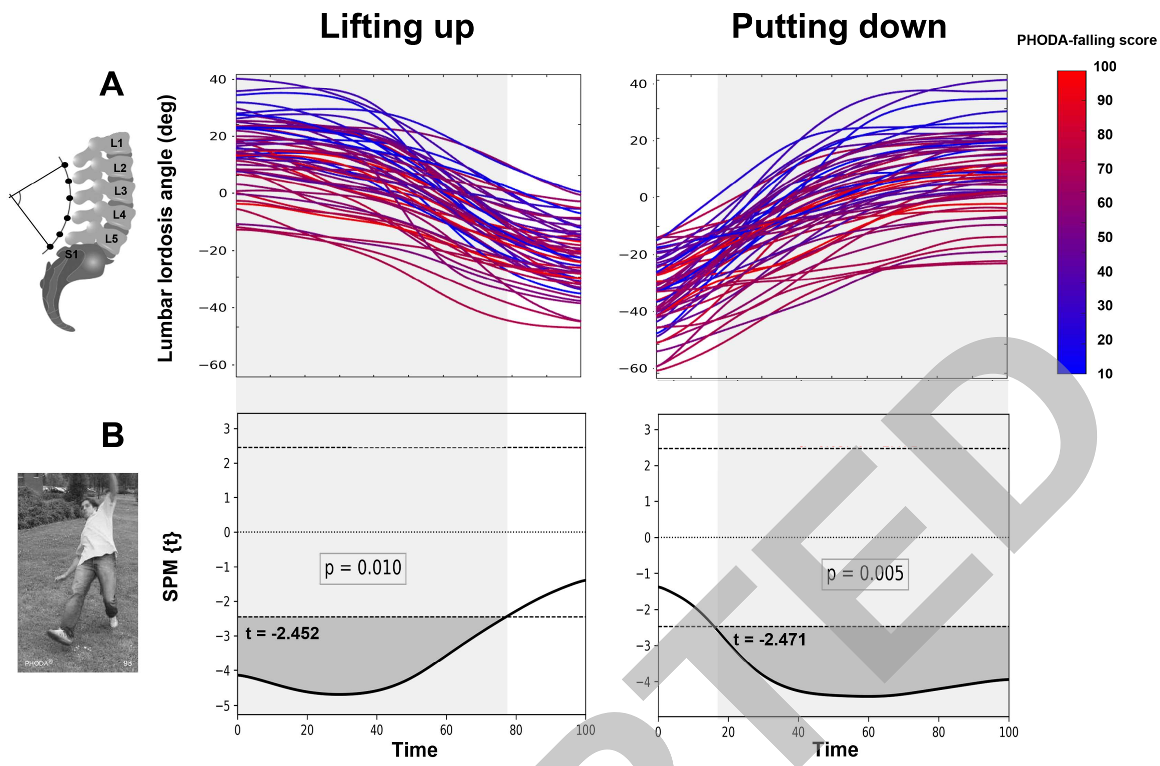
* indicates the markers used to calculate the regional angle (i.e. angle between the normal lines passing through the respective markers)


A
B


Lifting up
Putting down
PHODA-lift score
A
B
L1
L2
L3
L4
L5
S1
Lumbar lordosis angle (deg)
SPM {t}
p = 0.007
p = 0.028
t = -2.455
t = -2.470
PHODA



Lifting up
Putting down
PHODA-lift score
A
B
L1
L2
L3
L4
L5
S1
Angle between L4 and L5 markers
SPM {t}
p = 0.021
p = 0.012
t = -2.430
t = -2.451
Time
Time


Lifting up
Putting down
PHODA-falling score
A
B
L1
L2
L3
L4
L5
S1
Lumbar lordosis angle (deg)
SPM {t}
p = 0.010
t = -2.452
p = 0.005
t = -2.471
Time
Time
PHODA®