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scientific reports

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Task-specific pain-related fear influences lifting biomechanics differently in individuals with and without occupations involving repetitive lifting tasks

Christian Bangerter[1,2]✉, Oliver Faude[2], Denise Weidinger[1], André Meichtry[1], Michael L. Meier[3], Carol-Claudius Hasler[4,5] & Stefan Schmid[1,5]

Higher task-specific pain-related fear has been linked to restricted lumbar spine range of motion (ROM) during lightweight object lifting in chronic low back pain (LBP) patients and reduced lumbar spine flexion angles in healthy individuals, suggesting protective movement strategies. However, it remains unclear whether these findings apply to individuals who repetitively lift heavier objects at work. This study aimed to determine whether the effect of task-specific pain-related fear on lifting kinematics differs between individuals with (LIFTER) and without (NON-LIFTER) occupations involving repetitive lifting, and to quantify how this effect depends on object weight, task (lifting or lowering), and LBP history. 156 healthy individuals provided information on previous LBP episodes, completed pain-related fear questionnaires, and lifted 5-kg and 15-kg boxes. Kinematic outcomes included lumbar spine ROM and whole-body lifting strategy. Linear mixed models revealed that the effect of task-specific pain-related fear on lumbar spine ROM significantly differed between group (NON-LIFTER vs. LIFTER: -0.087), weight (5 kg vs. 15 kg: 0.026), and task (lifting vs. lowering: 0.059), but not LBP history (No LBP vs. LBP: -0.005). Higher task-specific pain-related fear was associated with reduced lumbar spine ROM in NON-LIFTER but not in LIFTER, suggesting that fear-driven protective movement strategies vary by occupation.

Keywords Object lifting, Psychomotor interactions, Fear-avoidance beliefs, Spine, Stoop-Squat-Index, Low back pain

Low back pain (LBP) is a major global health problem, affecting approximately 80% of individuals during their lifetime[1–3]. To prevent LBP, healthcare professionals commonly recommend lifting objects by squatting down while maintaining the spine in a neutral position (squat lifting)[4]. However, this advice warrants reconsideration, as there is no compelling evidence that avoiding spinal flexion during lifting prevents LBP or reduces spinal loading[5–8]. In fact, squat lifting may even increase compressive and shear loads on the lower lumbar spine, a region particularly vulnerable to injury and pain[8–10].

Beyond biomechanical concerns, an excessive emphasis on squatting during lifting may also have psychological repercussions. Negative beliefs about the back are prevalent, with both LBP patients and healthy individuals believing that lifting with a rounded back is harmful[11–13]. This overemphasis on avoiding spinal flexion could reinforce negative beliefs about the back and exacerbate pain-related fear[14], a recognized risk factor for the development and persistence of LBP[15–17].

Higher levels of lifting-specific pain-related fear have been linked to restricted lumbar spine range of motion (ROM) in chronic LBP patients[18], and reduced lumbar spine flexion angles in healthy, pain-free individuals[14].

[1]Spinal Movement Biomechanics Group, Division of Physiotherapy, School of Health Professions, Bern University of Applied Sciences, Murtenstrasse 10, 3008 Bern, Switzerland. [2]Department of Sport, Exercise and Health, University of Basel, Basel, Switzerland. [3]Integrative Spinal Research, Department of Chiropractic Medicine, Balgrist University Hospital, University of Zurich, Zurich, Switzerland. [4]Orthopaedic Department, University Children's Hospital of Basel, Basel, Switzerland. [5]Faculty of Medicine, University of Basel, Basel, Switzerland. ✉email: christian.bangerter@bfh.ch

These behavioral adaptations have been associated with a protective movement strategy, involving a stiffening of the spine through increased muscle co-activation, which may lead to increased spinal loading and muscle fatigue, potentially predisposing individuals to back problems in the long term[19–23]. However, as Knechtle et al.[14] examined lumbar spine angles during 5-kg box lifting, in a laboratory setting with a general population sample, it remains unclear whether these findings also apply to individuals who repetitively lift heavier objects at work. Previous research has linked higher frequency and intensity of lifting to an increased risk of LBP[24–27], underscoring the importance of further investigation in manual workers.

A recent systematic review highlighted the need for field-based studies measuring spinal kinematics in manual workers, addressing common limitations of existing studies, such as small sample sizes, reliance on laboratory settings, inaccurate measures of spinal motion, and the focus on lightweight lifting tasks[6]. To enhance the assessment of lifting behavior, even in field observations, it has been recommended to combine spinal flexion measures with evaluations of whole-body lifting strategies, such as the Stoop-Squat-Index[28], which can accurately and reliably be derived from conventional video recordings[29]. Moreover, research has shown that a history of LBP is not only a risk factor for future LBP[30] but may also influence lumbar spine motion during lifting[31], emphasizing the need to account for this factor when assessing lifting kinematics.

To address the identified gaps, the present study targeted individuals with and without occupations involving repetitive lifting, conducted field-based measurements, included varying lifting weights, and accounted for previous LBP episodes. The primary objective of this study was to determine whether the effect of task-specific pain-related fear on lifting kinematics differs between individuals with and without occupations involving repetitive lifting tasks. Additionally, the study aimed to quantify how this effect depends on object weight, whether the object is lifted or lowered, and LBP history.

Methods

Participants

This cross-sectional observational study included 156 healthy, pain-free adults, who were divided into two groups: LIFTER ($n=76$) and NON-LIFTER ($n=80$). The LIFTER group was defined as individuals whose occupation required daily repetitive bending and lifting of objects as an integral and unavoidable part of their work. Specifically, these participants were recruited from the employees working in the mail or parcel distribution centers of Switzerland's national postal service (Swiss Post), where handling of parcels involves frequent lifting and lowering tasks performed multiple times per day. This definition was restricted to occupational lifting, and activities outside of work (e.g., during leisure time or household tasks) were not considered. While the exact number of lifts and the weight of the parcels varied between individuals and workdays, these criteria ensured that all LIFTER were regularly exposed to frequent occupational lifting demands, thereby distinguishing them from individuals without such occupational lifting exposure. The NON-LIFTER group was defined as individuals whose occupations did not involve repetitive lifting or bending tasks (e.g., office workers) and were recruited from the Swiss general population.

All participants were recruited between March 2023 and May 2024, based on the following inclusion criteria: aged between 18 and 60 years, healthy and free of current lumbar back pain, and sufficient understanding of the German language. Exclusion criteria were: acute LBP episodes in the last 3 months and/or history of chronic LBP (pain lasting more than 3 months), diseases, comorbidities, injuries, surgeries, and other conditions limiting lifting capability, prior surgical interventions of the spine, known pregnancy or breastfeeding, and obesity.

The study was performed in accordance with the Declaration of Helsinki and was approved by the responsible ethics committee (Kantonale Ethikkommission Bern, Project-ID: 2022 – 01607). All participants provided written informed consent prior to the data collection.

Procedures

All participants completed a single measurement session. For LIFTER, measurements took place in closed rooms (e.g., break rooms) at the respective mail and parcel distribution centers. For NON-LIFTER, measurements were carried out in various office spaces. All measurements were conducted by the same experienced physical therapist, with partial assistance from a second physical therapist of equal experience to ensure smooth and timely completion.

Medical history and psychological questionnaires

Participants first answered questions about demographics and previous LBP episodes. Specifically, LBP history was dichotomized and assessed with the question: "Have you ever experienced low back pain in your life?" If participants asked for clarification on what should be considered LBP, they were instructed to consider any pain that had limited or interfered with their daily activities. We did not collect additional information on the number of previous episodes, the time since the last episode, or the specific movements provoking pain. Following this, they completed the following three validated questionnaires to assess self-reported measures of pain-related fear and general anxiety:

Tampa Scale for Kinesiophobia for the General Population (TSK-G).

This 17-item questionnaire evaluates fear of movement or (re)injury. Each statement is rated on a 4-point Likert scale from 1 (strongly disagree) to 4 (strongly agree), resulting in a total score ranging from 17 to 68. Higher scores indicate greater levels of fear of movement or (re)injury[32,33]. The total score (TSK-total) was used as a measure of general pain-related fear[14,18,32].

Photograph Series of Daily Activities – Short electronic Version (PHODA-SeV).

This tool assesses the perceived harmfulness of various physical activities. Participants were shown 40 photographs of everyday activities on a laptop and asked to imagine performing each activity, then rate how harmful they believed it would be to their back on a scale from 0 (not harmful at all) to 100 (extremely harmful)[34].

The score for item number 3 of the PHODA-SeV, depicting a person lifting a flowerpot with a rounded back (PHODA-lift), was used as a measure of task-specific pain-related fear during object lifting[14,18,35].

State-Trait Anxiety Inventory (STAI).

This questionnaire comprises two subscales to assess anxiety: state anxiety (S-Anxiety) evaluates momentary feelings of anxiety, while trait anxiety (T-Anxiety) measures the general tendency to experience anxiety[36,37]. Each subscale includes 20 items rated on a 4-point Likert scale from 1 ("not at all" or "almost never") to 4 ("very much so" or "almost always"). The total scores for each subscale range from 20 to 80, with higher values indicating greater levels of anxiety[36,37]. The total scores of the S-Anxiety (STATE-total) and T-Anxiety (TRAIT-total) subscales were used as measures of general anxiety.

Assessment of lifting kinematics

After completing the questionnaires, a biomechanical assessment of object lifting was conducted, involving the quantification of lumbar spine kinematics and whole-body lifting strategy using portable measurement equipment.

Lumbar spine kinematics were assessed using the Epionics SPINE system (MCG motion capture GmbH, Heidelberg, Germany), a wearable strain gauge-based system measuring at a sampling rate of 50 Hz. Two hollow, elastic adhesive tapes were attached to the skin on both sides along the spine, 3 cm lateral to the spinous processes, starting at the level of a line connecting the posterior superior iliac spines. The distance from this line to the spinous process of the 12th thoracic vertebra (Th12-distance) was measured using a tape measure to determine the number of sensors required to capture lumbar spine motion. Flexible sensor strips, each containing 12 vertically arranged strain gauge sensors (2.5 cm in length) and two acceleration sensors positioned at the upper and lower ends, were inserted into the adhesive tapes. These strips were connected to a compact storage unit (12.5 × 5.6 × 2 cm, 80 g), which was worn on an elastic belt around the pelvis. The Epionics SPINE system has been validated in a previous study, demonstrating reliable and accurate measurements of sagittal plane lumbar spine angles during an object lifting task, compared with a Vicon motion capture system[38].

Whole-body lifting strategy was assessed through conventional lateral-view video recordings, captured with an iPad Air (Apple Inc., Cupertino, CA, USA) at a frame rate of 60 Hz[29]. To facilitate the identification of specific anatomical landmarks required for subsequent analyses, retro-reflective skin markers were attached to the left greater trochanter as well as the tip of the C7 spinous process. The iPad was mounted on a tripod positioned 3 m lateral to the participants on the left side, with the camera height set at 85 cm above the ground and aligned perpendicularly to the participants' sagittal plane when performing the lifting task. A T-shaped adhesive tape was placed on the floor to standardize the participants' stance, with their toes aligned behind the front tape and their heels equidistant from the middle tape[29].

Participants lifted and lowered a box, once with a weight of 5 kg, and once with 15 kg, using a freestyle technique. They were instructed to lift and lower the box intuitively at their preferred speed, using a movement pattern consistent with their usual daily lifting behavior. However, as participants were informed about the study's objectives, they were aware that their lifting technique would be studied. The box (40 × 20 × 10 cm), equipped with handles, was placed on the floor 15 cm in front of the participants' toes[8,14,29]. To minimize the impact of potential habituation effects or fatigue, the order of the weight conditions (i.e., whether to start with 5 kg or 15 kg) was randomized, and participants were allowed to perform one practice lift in each weight condition. For each weight condition, data from the iPad and the Epionics SPINE system were recorded simultaneously until five valid trials were completed. A trial was considered valid if the movement sequence was completed without interruptions such as balance loss, slipping from the box handles, turning the head, or other hesitations. To synchronize the two measurement systems, participants performed a rapid heel-rise movement (synchronization movement) at the start of each weight condition.

Data reduction and parameters of interest

Parameters of interest from the questionnaires, including general pain-related fear (TSK-total), task-specific pain-related fear (PHODA-lift), and general anxiety (STATE-total, TRAIT-total), were calculated according to the respective scoring manuals.

Data from the Epionics SPINE system were processed using a custom-built MATLAB routine (R2022a, MathWorks Inc., Natick, MA, USA)[38]. An event detection function was used to automatically identify the start of the two movement sequences (T0), each consisting of five lifting and lowering repetitions, based on the acceleration data of the synchronization movement. All other temporal events (i.e., the events indicating the start and end of each lifting and lowering task) were adopted from the video analysis, as described below. Subsequently, angle data derived from each strain gauge were smoothed using a zero-phase Butterworth low-pass filter with a 6 Hz cutoff frequency. To determine the sagittal plane lumbar spine angle, the filtered angle data from all strain gauge sensors up to the Th12-distance were summed for each sensor strip and averaged between the two strips. In case of erroneous data from one strip (e.g., due to tape displacement, detachment, or technical defects), only the summed angle data from the other strip were used.

Video recordings were processed using the Dartfish software (Dartfish 2022, Version 11.0, Dartfish company, Freiburg, Switzerland; https://www.dartfish.com), following a standardized and validated protocol for deriving whole-body lifting strategies[29]. A two-dimensional coordinate system was established with its origin at the intersection of the T-shaped tape on the floor, using the participants' body height as the reference distance. The markers placed on the greater trochanter and the C7 spinous process were automatically tracked by the software, with manual corrections applied as needed, and the vertical positions of these markers were extracted relative to the coordinate system origin. The start of the two movement sequences (T0), defined by the synchronization movement, and the start of each lifting and the end of each lowering task, defined by the box movement (i.e., start when the box began moving and end when the box stopped moving), were manually identified. The end of the lifting and the start of the lowering task were automatically identified using a MATLAB-based event detection function based on the vertical trajectory of the C7 marker[28,29,38]. Whole-body lifting strategies were quantified using the Stoop-Squat-Index, calculated for each lifting and lowering task based on the vertical positions of the greater trochanter and C7 markers[28]. The Stoop-Squat-Index ranges from 0, representing a full squat strategy, to 100, representing a full stoop strategy[28].

Kinematic data for each lifting and lowering task were then time-normalized to 101 data points. To allow for further analyses, the sagittal lumbar spine angles were parameterized into ROM by calculating the absolute difference between the maximum and the minimum angles within each task. Stoop-Squat-Indices were parameterized as their values at 30% of the lifting and 70% of the lowering task as previously recommended by Bangerter et al.[29]. All parameters were finally averaged across the five repetitions per weight condition and task, resulting in four lumbar spine ROM values and four Stoop-Squat-Index values per participant.

Statistical analysis

Descriptive statistics were calculated for demographics, psychological questionnaire scores, and lifting kinematics. Normality of the data was assessed using the Shapiro-Wilk test and visual inspection of Q-Q plots. As several variables were not normally distributed, group differences between LIFTER and NON-LIFTER were tested using Mann-Whitney U tests or Chi-Square tests (for dichotomous variables). In addition, associations between measures of pain-related fear and general anxiety were evaluated using Spearman's rank correlation coefficients, with bootstrap 95% confidence intervals computed from 5000 resamples.

To examine the effect of task-specific pain-related fear on lifting kinematics, a linear mixed model was fitted for each outcome of interest (i.e., lumbar spine ROM and Stoop-Squat-Index). Fixed effects included PHODA-lift as the primary regressor of interest; Task (lifting or lowering) and Weight (5 kg or 15 kg) as within-subject factors; Group (LIFTER or NON-LIFTER) and LBP history (LBP or No LBP) as between-subject factors; and the interaction terms between PHODA-lift and each of these factors. To account for the correlation structure of the data, random intercepts were included for Subject, Subject:Weight, and Subject:Task.

The models were adjusted for the potential confounding variables age, sex, BMI, and TSK-total[14,18,35,39]. TSK-total was included to account for linear effects of general pain-related fear. Since TSK-total significantly correlated with both measures of general anxiety (STATE-total and TRAIT-total), these two variables were not added to the models. From the fitted models, we computed contrasts of interest to examine differences in the PHODA-lift effect with respect to Group, Task, Weight, and LBP history. Moreover, we derived model-based predictions for the different subgroups defined by all 16 combinations with respect to Group, Task, Weight, and LBP history. Residual analysis was performed to check model assumptions. Statistical significance was determined at an alpha level of 0.05. All statistical analyses were conducted in R (R Core Team, 2024, version 4.4.2)[40], using the "boot"[41,42], "lme4"[43], "lmerTest"[44], "emmeans"[45], and "effects"[46–48] packages.

Results

The LIFTER group ($n = 76$) was older, taller, had a greater mass and BMI, and included more males than the NON-LIFTER group ($n = 80$). No significant differences were observed in LBP history, with 33 participants in each group reporting no prior LBP. A detailed overview of participants' demographics, psychological questionnaire scores, and lifting kinematics for the total sample and by group is provided in Table 1.

The LIFTER group scored significantly higher on all psychological questionnaires assessing pain-related fear and general anxiety, except for the TRAIT-total score. The median PHODA-lift scores were 80 for LIFTER (mean: 69.5) and 60 for NON-LIFTER (mean: 53.1). A correlation matrix of pain-related fear and general anxiety measures is shown in the Supplementary Table S1. The PHODA-lift, as measure of task-specific pain-related fear, did not significantly correlate with the other questionnaire scores ($r_s \leq 0.089$). The TSK-total, as measure of general pain-related fear, demonstrated significant correlations with the STATE-total, and the TRAIT-total ($r_s \geq 0.159$).

Lumbar spine ROM data were unavailable for two participants (both from the LIFTER group) due to technical issues with the Epionics SPINE system. Consequently, we had 616 ($154 \times 2 \times 2$) observations for lumbar spine ROM and 624 ($156 \times 2 \times 2$) observations for the Stoop-Squat-Index. With 18 parameters to be estimated per model, this resulted in approximately 34 observations per estimated parameter, indicating sufficient statistical precision. Residual analyses showed no evidence against model assumptions.

Effect of task-specific pain-related fear on lumbar spine ROM

The linear mixed model for lumbar spine ROM revealed statistically significant interaction effects for PHODA-lift:Group ($p = 0.039$), PHODA-lift:Task ($p = 0.001$), and PHODA-lift:Weight ($p = 0.006$). No significant interaction effect was observed for PHODA-lift:LBP history ($p = 0.897$). A detailed output of the fitted linear mixed model for lumbar spine ROM is presented in Table 2. PHODA-lift trends and contrasts of interest are summarized in Table 3.

The difference in the PHODA-lift effect between the groups (NON-LIFTER vs. LIFTER) was statistically significant (contrast: -0.087, $p = 0.039$). In the NON-LIFTER group, the PHODA-lift demonstrated a statistically significant negative effect on lumbar spine ROM (estimate: -0.081, $p = 0.007$). In contrast, no evidence of a PHODA-lift effect was observed in the LIFTER group (estimate: 0.007, $p = 0.825$).

The difference in the PHODA-lift effect between the tasks (lifting vs. lowering) was statistically significant (0.059, $p = 0.001$). For the lifting task, no evidence of a PHODA-lift effect was observed (-0.007, $p = 0.747$). For the lowering task, the PHODA-lift demonstrated a statistically significant negative effect on lumbar spine ROM (-0.067, $p = 0.004$).

The difference in the PHODA-lift effect between the weight conditions (5 kg vs. 15 kg) was statistically significant (0.026, $p = 0.006$). For the 5-kg weight, no evidence of a PHODA-lift effect was observed (-0.024,

			All ($n=156$)	LIFTER ($n=76$)	NON-LIFTER ($n=80$)	p-value
Demographics						
Sex [male (%) / female (%)]			96 (62) / 60 (38)	58 (76) / 18 (24)	38 (47.5) / 42 (52.5)	**< 0.001**[a]
Age [years]			38.7 ± 11.8	41.3 ± 11.7	36.3 ± 11.4	**0.009**
Height [cm]			173.8 ± 9.1	175.1 ± 8.6	172.6 ± 9.3	**0.042**
Mass [kg]			74.3 ± 13.4	77.2 ± 13.0	71.5 ± 13.3	**0.008**
BMI [kg/m^2]			24.5 ± 3.2	25.1 ± 3.3	23.8 ± 2.9	**0.035**
LBP history [LBP (%) / No LBP (%)]			90 (58) / 66 (42)	43 (57) / 33 (43)	47 (59) / 33 (41)	0.784[a]
Psychological questionnaires						
PHODA-lift			65 (40–85)	80 (51–90)	60 (30–74)	**< 0.001**
TSK-total			33 (30–39)	35 (31–41)	32 (28–36)	**0.001**
STATE-total			29 (25–33)	30 (25–36)	28 (25–31)	**0.049**
TRAIT-total			31 (26–37)	32 (27–37)	31 (26–37)	0.745
Lifting kinematics						
Lumbar spine ROM [°]	lifting	5 kg	27.2 ± 7.7	29.2 ± 7.8	25.3 ± 7.1	
		15 kg	26.3 ± 7.9	28.3 ± 8.2	24.5 ± 7.1	
	lowering	5 kg	30.8 ± 7.8	30.1 ± 7.4	31.5 ± 8.2	
		15 kg	30.0 ± 8.0	29.2 ± 7.4	30.7 ± 8.5	
Stoop-Squat-Index	lifting	5 kg	51.8 ± 20.8	49.6 ± 23.3	53.9 ± 18.1	
		15 kg	45.3 ± 18.7	45.2 ± 20.6	45.4 ± 16.9	
	lowering	5 kg	50.9 ± 22.3	48.3 ± 24.1	53.4 ± 20.2	
		15 kg	42.3 ± 20.8	41.8 ± 22.0	42.8 ± 19.6	

Table 1. Demographics, psychological questionnaire scores, lumbar spine range of motion (ROM), and Stoop-Squat-Index for the total sample and by group (LIFTER and NON-LIFTER). Values are presented as mean ± SD or median (25th -75th percentile). Group comparisons were conducted using Mann-Whitney U tests for continuous variables and Chi-Square tests ([a]) for dichotomous variables. Statistically significant differences ($p < 0.05$) are marked in bold. PHODA-lift: Score for item 3 of the Photograph Series of Daily Activities – Short electronic Version (PHODA-SeV). TSK-total: Total score of the Tampa Scale for Kinesiophobia for the General Population (TSK-G). STATE-total: Total score of the state anxiety subscale from the State-Trait Anxiety Inventory (STAI). TRAIT-total: Total score of the trait anxiety subscale from the STAI.

$p = 0.266$). For the 15-kg weight, the PHODA-lift demonstrated a statistically significant effect on lumbar spine ROM (-0.050, $p = 0.022$).

Figure 1 presents model-based predictions and illustrates the dependence of the PHODA-lift effect on the different subgroups, with the corresponding PHODA-lift trends provided in Table 4. The following Eq. (1) estimates the PHODA-lift effect on lumbar spine ROM as a linear function of Group, Task, Weight, and LBP history:

$$PHODA-lift\,effect = -0.037 + 0.044\ (Group) - 0.030\ (Task) - 0.013\ (Weight) + 0.003\ (LBP\ history) \quad (1)$$

where Group, Task, Weight, and LBP history are coded as follows (2):

$$Group = \begin{cases} 1, & if\ LIFTER \\ -1, & if\ NON-LIFTER \end{cases} \quad Task = \begin{cases} 1, & if\ lowering \\ -1, & if\ lifting \end{cases}$$
$$Weight = \begin{cases} 1, & if\ 15\ kg \\ -1, & if\ 5\ kg \end{cases} \quad LBP\ history = \begin{cases} 1, & if\ LBP \\ -1, & if\ No\ LBP \end{cases} \quad (2)$$

Effect of task-specific pain-related fear on Stoop-Squat-Index

The linear mixed model for the Stoop-Squat-Index demonstrated no statistically significant interaction effects for PHODA-lift:Group ($p = 0.597$), PHODA-lift:Task ($p = 0.890$), PHODA-lift:Weight ($p = 0.553$), and PHODA-lift:LBP history ($p = 0.734$). A detailed output of the fitted linear mixed model for the Stoop-Squat-Index is presented in Table 5. PHODA-lift trends and contrasts of interest are summarized in Table 6. The overall PHODA-lift trend on the Stoop-Squat-Index was estimated at -0.093 ($p = 0.124$). Figure 2 presents model-based predictions and illustrates the dependence of the PHODA-lift effect on the different subgroups, with the corresponding PHODA-lift trends provided in the Supplementary Table S2. The following Eq. (3) estimates the PHODA-lift effect on the Stoop-Squat-Index as a linear function of Group, Task, Weight, and LBP history (with the same coding as specified above):

$$PHODA-lift\,effect = -0.093 + 0.032\ (Group) - 0.001\ (Task) + 0.013\ (Weight) - 0.020\ (LBP\ history) \quad (3)$$

Random effects	Variance	SD
Subject:Weight (Intercept)	1.94	1.39
Subject:Task (Intercept)	15.90	3.99
Subject (Intercept)	32.50	5.70
Residual	6.31	2.51

Fixed effects	Estimate	SE	t-value	p-value
Intercept	25.508	5.897	4.33	**< 0.001**
PHODA-lift	−0.037	0.021	−1.76	0.081
Group (LIFTER)	−2.173	1.429	−1.52	0.130
Task (lowering)	3.640	0.607	5.99	**< 0.001**
Weight (15 kg)	0.365	0.314	1.16	0.247
LBP history (LBP)	−1.243	1.319	−0.94	0.348
Sex (female)	−0.931	0.618	−1.51	0.134
Age	−0.036	0.047	−0.76	0.449
BMI	0.160	0.178	0.90	0.371
TSK-total	0.071	0.084	0.85	0.396
PHODA-lift:Group (LIFTER)	0.044	0.021	2.08	**0.039**
PHODA-lift:Task (lowering)	−0.030	0.009	−3.26	**0.001**
PHODA-lift:Weight (15 kg)	−0.013	0.005	−2.76	**0.006**
PHODA-lift:LBP history (LBP)	0.003	0.020	0.13	0.897

Table 2. Fitted linear mixed model for lumbar spine range of motion. Categorical variables were coded using sum-to-zero contrasts. Statistical significance ($p < 0.05$) is indicated in bold. SD: standard deviation. SE: standard error.

		Estimate	SE	Lower CL	Upper CL	t-value	*p*-value
Overall		−0.037	0.021	−0.079	0.005	−1.759	0.081
Group	LIFTER	0.007	0.030	−0.053	0.066	0.221	0.825
	NON-LIFTER	−0.081	0.030	−0.139	−0.022	−2.730	**0.007**
	contrast (NON-LIFTER vs. LIFTER)	−0.087	0.042	−0.170	−0.004	−2.081	**0.039**
Task	lowering	−0.067	0.023	−0.112	−0.022	−2.908	**0.004**
	lifting	−0.007	0.023	−0.053	0.038	−0.323	0.747
	contrast (lifting vs. lowering)	0.059	0.018	0.023	0.095	3.264	**0.001**
Weight	15 kg	−0.050	0.022	−0.093	−0.007	−2.318	**0.022**
	5 kg	−0.024	0.022	−0.067	0.019	−1.115	0.266
	contrast (5 kg vs. 15 kg)	0.026	0.009	0.007	0.045	2.764	**0.006**
LBP history	LBP	−0.035	0.026	−0.086	0.018	−1.311	0.192
	No LBP	−0.040	0.032	−0.102	0.023	−1.252	0.213
	contrast (No LBP vs. LBP)	−0.005	0.040	−0.085	0.074	−0.130	0.897

Table 3. Estimated PHODA-lift trends and contrasts of interest for lumbar spine range of motion. Values are presented overall and by Group, Task, Weight, and LBP history, along with corresponding contrasts of interest derived from the fitted linear mixed model. Statistical significance ($p < 0.05$) is indicated in bold. SE: standard error. CL: 95% confidence limit.

Discussion

This study investigated whether task-specific pain-related fear influences lifting kinematics differently in individuals with and without occupations involving repetitive lifting. Additionally, we examined how this effect varies based on object weight, movement task (lifting or lowering), and LBP history. The results showed that the PHODA-lift effect on lumbar spine ROM significantly differed between Group (LIFTER vs. NON-LIFTER), Task (lifting vs. lowering), and Weight (5 kg vs. 15 kg), but not LBP history (LBP vs. No LBP). Specifically, a significant negative PHODA-lift effect on lumbar spine ROM was observed in the NON-LIFTER group, during the lowering task, and with the 15-kg weight. In contrast, no significant differences in the PHODA-lift effect on whole-body lifting strategy were observed between Group, Task, Weight, and LBP history.

Effect of task-specific pain-related fear on lumbar spine ROM

The PHODA-lift effect on lumbar spine ROM differed between LIFTER and NON-LIFTER, suggesting that task-specific pain-related fear affects lumbar spine ROM differently in individuals with and without repetitive

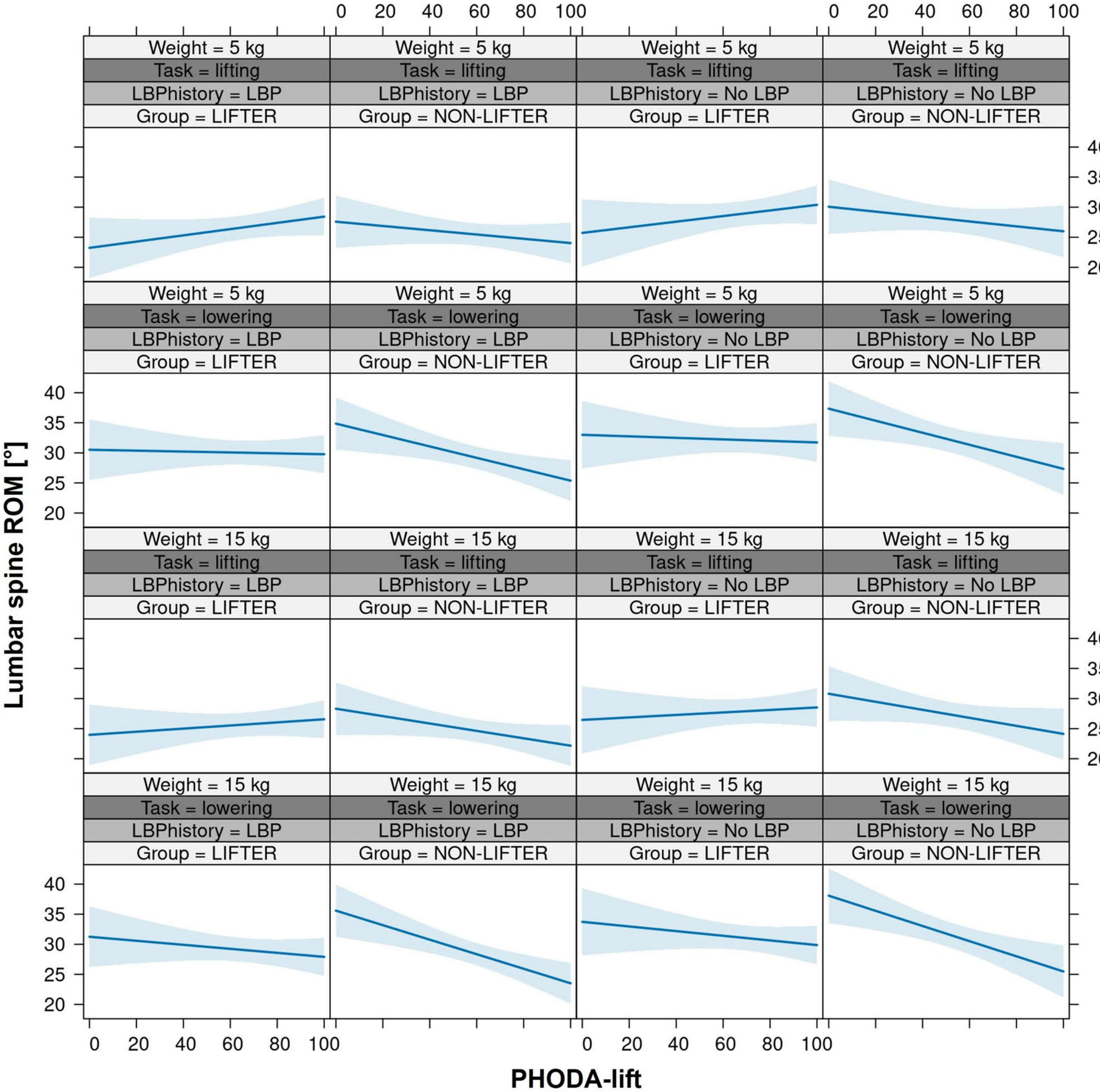

Fig. 1. Predictor effect plot illustrating the effect of PHODA-lift (x-axis) on lumbar spine range of motion (ROM) in degrees [°] (y-axis), across different subgroups defined by all combinations of Group (LIFTER or NON-LIFTER), Task (lifting or lowering), Weight (5 or 15 kg), and LBP history (LBP or No LBP). Columns are sorted by LBP history and Group, and rows by Weight and Task. Model-based predictions for lumbar spine ROM are shown as blue solid lines, with 95% confidence intervals represented by blue shaded areas.

occupational lifting tasks. Specifically, NON-LIFTER exhibited a significant decrease in lumbar spine ROM with higher PHODA-lift scores, whereas LIFTER did not. More precisely, in NON-LIFTER, a PHODA-lift score of 100 corresponded to an average reduction of 8.1 degrees in lumbar spine ROM compared to a score of 0. This negative association in NON-LIFTER aligns with previous studies[14,18]. For example, in chronic LBP patients, higher PHODA-lift scores were linked to reduced lumbar spine ROM during a 4-kg box-lifting task[18]. Similarly, Knechtle et al.[14] observed negative relationships between task-specific pain-related fear and lumbar spine flexion angles during 5-kg object lifting in healthy, pain-free individuals. Based on previous evidence, this reduction in lumbar spine ROM in NON-LIFTER with higher lifting-specific pain-related fear may reflect a protective movement strategy, consisting of a trunk-stiffening mechanism to safeguard the spine by limiting lumbar motion[14,18,22]. Although such strategies, likely driven by increased muscle co-contraction, may provide short-term benefits for LBP patients, their persistence could lead to muscle fatigue and increased spinal loading, potentially increasing the risk of back problems over time[19–23,49].

Group	Task	Weight	LBP history	Estimate	SE	Lower CL	Upper CL	t-value	*p*-value
LIFTER	lifting	5 kg	LBP	0.052	0.036	−0.019	0.123	1.45	0.150
			No LBP	0.047	0.039	−0.030	0.124	1.20	0.233
		15 kg	LBP	0.026	0.036	−0.045	0.097	0.72	0.471
			No LBP	0.021	0.039	−0.056	0.098	0.53	0.597
	lowering	5 kg	LBP	−0.007	0.036	−0.078	0.063	−0.21	0.836
			No LBP	−0.013	0.039	−0.090	0.064	−0.33	0.746
		15 kg	LBP	−0.033	0.036	−0.104	0.037	−0.93	0.353
			No LBP	−0.039	0.039	−0.116	0.038	−0.99	0.323
NON-LIFTER	lifting	5 kg	LBP	−0.036	0.034	−0.104	0.033	−1.03	0.304
			No LBP	−0.041	0.040	−0.119	0.038	−1.02	0.307
		15 kg	LBP	−0.062	0.034	−0.129	0.007	−1.79	0.076
			No LBP	−0.067	0.040	−0.145	0.012	−1.68	0.095
	lowering	5 kg	LBP	−0.095	0.034	−0.163	−0.027	−2.75	**0.007**
			No LBP	−0.100	0.040	−0.179	−0.022	−2.52	**0.013**
		15 kg	LBP	−0.121	0.034	−0.189	−0.053	−3.51	**< 0.001**
			No LBP	−0.126	0.040	−0.205	−0.048	−3.17	**0.002**

Table 4. Estimated PHODA-lift trends for lumbar spine range of motion across all subgroups. Statistical significance ($p < 0.05$) is indicated in bold. SE: standard error. CL: 95% confidence limit.

The absence of evidence for a PHODA-lift effect on lumbar spine ROM in LIFTER could be explained by their occupational experience. Accustomed to handling heavier loads daily, these individuals may not perceive the lifting tasks in this study as threatening and thus may not adopt fear-driven protective movement strategies. However, this explanation is challenged by the significantly higher PHODA-lift scores in LIFTER (mean: 69.5) compared to NON-LIFTER (mean: 53.1), which indicate heightened lifting-specific pain-related fear. Although PHODA-lift scores in the entire sample were generally higher than those reported in previous studies involving healthy, pain-free individuals from the general population (mean scores of 47.5[14] and 42.5[35]), the PHODA-lift scores in LIFTER were comparable to those observed in chronic LBP patients, who demonstrated mean scores of 72.9[18] and 71.4[34]. These elevated PHODA-lift scores in LIFTER suggest a strong belief that lifting with a rounded back is dangerous. This belief may be learned and reinforced through occupational manual handling training, as many physical therapists and manual handling advisors continue to advocate lifting with a straight back while advising against spinal flexion during lifting[4]. Such recommendations could foster negative beliefs about spinal health and contribute to pain-related fear, potentially explaining the high PHODA-lift scores in LIFTER. However, the lack of a significant PHODA-lift effect in LIFTER suggests that this explicit belief did not translate into altered lifting behavior. Further research is warranted to elucidate the underlying mechanisms of this psychomotor decoupling.

Moreover, the PHODA-lift effect on lumbar spine ROM significantly varied between lifting and lowering tasks, and between 5-kg and 15-kg weights. Although a negative PHODA-lift effect was observed across both tasks and weights, indicating reduced lumbar spine ROM with higher task-specific pain-related fear, the effect was more pronounced and only reached statistical significance during the lowering task and with the 15-kg weight. This suggests that protective movement strategies were primarily adopted when lowering heavier loads, likely reflecting increased caution in response to higher perceived risk. These findings partially contradict Knechtle et al.[14], who reported significant negative associations between PHODA-lift and lumbar spine flexion angles throughout most of both the lifting and lowering tasks but not with discrete lumbar spine ROM values. However, direct comparisons with Knechtle et al.[14] and Matheve et al.[18] are difficult, as neither study included heavier loads nor separately analyzed lumbar spine ROM for the lifting and lowering tasks.

The results showed no significant differences in the PHODA-lift effect on lumbar spine ROM between individuals with and without an LBP history. This suggests that there is no evidence that previous LBP episodes influence the relationship between psychological factors and spinal motion. One possible explanation is the absence of chronic conditions in the current sample, as all participants were pain-free at the time of testing, despite more than half reporting previous LBP episodes. However, this finding is somewhat unexpected, as according to the fear-avoidance model, an LBP episode could potentially increase pain-related fear[15,17,50,51], and previous research has indicated that manual workers with a history of LBP use less lumbar spine flexion during lifting than those without[31]. In addition, decreased lumbar spine ROM has been reported in individuals with recurrent LBP during a remission period[52].

Effect of task-specific pain-related fear on stoop-squat-index

The PHODA-lift effect on the Stoop-Squat-Index revealed no significant differences between LIFTER and NON-LIFTER, suggesting that occupation does not significantly influence the impact of task-specific pain-related fear on whole-body lifting strategies. Furthermore, this effect did not significantly vary between lifting and lowering tasks, 5-kg and 15-kg weights, or individuals with and without an LBP history. Across all subgroups, PHODA-lift exhibited a negative effect on the Stoop-Squat-Index, which was more pronounced in NON-LIFTER and among participants with an LBP history. While this effect did not reach statistical significance, it suggests that

Random effects	Variance	SD
Subject:Weight (Intercept)	105.1	10.25
Subject:Task (Intercept)	12.4	3.52
Subject (Intercept)	289.7	17.02
Residual	13.1	3.62

Fixed effects	Estimate	SE	t-value	p-value
Intercept	27.510	16.764	1.64	0.103
PHODA-lift	−0.093	0.060	−1.55	0.124
Group (LIFTER)	−2.143	4.066	−0.53	0.599
Task (lowering)	−0.881	0.605	−1.46	0.147
Weight (15 kg)	−4.587	1.468	−3.12	**0.002**
LBP history (LBP)	1.022	3.765	0.27	0.786
Sex (female)	3.138	1.765	1.78	0.078
Age	−0.105	0.134	−0.79	0.433
BMI	1.272	0.509	2.50	**0.013**
TSK-total	−0.023	0.235	−0.10	0.924
PHODA-lift:Group (LIFTER)	0.032	0.060	0.53	0.597
PHODA-lift:Task (lowering)	−0.001	0.009	−0.14	0.890
PHODA-lift:Weight (15 kg)	0.013	0.022	0.59	0.553
PHODA-lift:LBP history (LBP)	−0.020	0.057	−0.34	0.734

Table 5. Fitted linear mixed model for the Stoop-Squat-Index. Categorical variables were coded using sum-to-zero contrasts. Statistical significance ($p < 0.05$) is indicated in bold. SD: standard deviation. SE: standard error.

		Estimate	SE	Lower CL	Upper CL	t-value	*p*-value
Overall		−0.093	0.060	−0.212	0.026	−1.548	0.124
Group	LIFTER	−0.062	0.085	−0.230	0.107	−0.723	0.471
	NON-LIFTER	−0.125	0.085	−0.292	0.042	−1.477	0.142
	contrast (NON-LIFTER vs. LIFTER)	−0.063	0.120	−0.300	0.173	−0.530	0.597
Task	lowering	−0.095	0.061	−0.215	0.026	−1.552	0.123
	lifting	−0.092	0.061	−0.212	0.028	−1.511	0.133
	contrast (lifting vs. lowering)	0.003	0.018	−0.033	0.038	0.139	0.890
Weight	15 kg	−0.080	0.064	−0.207	0.046	−1.251	0.213
	5 kg	−0.106	0.064	−0.233	0.020	−1.658	0.099
	contrast (5 kg vs. 15 kg)	−0.026	0.044	−0.113	0.061	−0.595	0.553
LBP history	LBP	−0.113	0.075	−0.261	0.036	−1.504	0.135
	No LBP	−0.074	0.091	−0.253	0.105	−0.813	0.417
	contrast (No LBP vs. LBP)	0.039	0.115	−0.188	0.266	0.341	0.734

Table 6. Estimated PHODA-lift trends and contrasts of interest for the Stoop-Squat-Index. Values are presented overall and by Group, Task, Weight, and LBP history, along with corresponding contrasts of interest derived from the fitted linear mixed model. SE: standard error. CL: 95% confidence limit.

higher lifting-specific pain-related fear was associated with increased squatting behavior. Similar to fear-driven adaptations in lumbar spine motion[14,18], this shift towards squatting may reflect a protective movement strategy, whereby individuals engage the lower extremities more to move the load while maintaining a more upright trunk position, potentially to minimize spinal strain.

Unlike the findings for lumbar spine ROM, no significant association was observed between PHODA-lift and Stoop-Squat-Index. This may indicate that task-specific pain-related fear primarily affects lumbar spine motion, with a less clear influence on whole-body lifting strategies. In this context, it is important to note that the Stoop-Squat-Index quantifies the ratio between trunk forward lean and mainly knee joint flexion but does not provide any information on lumbar spine angles[28]. It could therefore be that a high Stoop-Squat-Index results from a trunk forward lean that is achieved through hip flexion rather than spinal flexion[28]. Nevertheless, the size of the estimated overall effect indicates that a PHODA-lift score of 100 corresponds to an average decrease of 9.3 in the Stoop-Squat-Index compared to a score of 0, suggesting potential clinical relevance.

Limitations

One limitation is the use of the Epionics SPINE system to quantify lumbar spine motion. This method relies on sensor strips placed on the skin lateral to the spine, which may not precisely capture the movement of the underlying bony structures. Nonetheless, this system has been validated for measuring lumbar spine ROM during box-lifting tasks, demonstrating accurate and reliable values compared with a Vicon motion capture system[38]. In addition, a limitation of our group definition (LIFTER vs. NON-LIFTER) is that lifting and bending activities performed during leisure time or household tasks were not assessed, and classification was therefore only based on occupational exposure. As a result, our findings are limited with respect to potential dose-effect relationships between total lifting exposure and the investigated outcomes. Another limitation is the reliance on self-reported LBP history, which is susceptible to recall bias. No data were collected on the intensity or duration of past LBP episodes, and participants determined whether previous back complaints were classified as pain. As a result, the dichotomous classification of LBP history was subjective, with a possible impact on the study's findings. The limited definition of LBP history may have resulted in subgroups of participants with very different LBP experiences (e.g., recurrent vs. single past episodes), potentially explaining differences between studies. Our finding that LBP history did not influence the effect of task-specific pain-related fear on lumbar spine ROM should therefore be interpreted with caution, as other definition criteria could lead to different results. In addition, the predefined object weights and the standardized stance did not allow for participant-specific adaptations based on body weight or height, potentially influencing the results. Finally, the presence of a physical therapist during measurements may have influenced participants' lifting behavior, a potential instance of the Hawthorne effect, where individuals modify behavior when they know they are being observed[53]. In motor behavior research, similar effects have been reported, such as changes in gait kinematics under observation[54,55]. Moreover, participants' awareness of both the study's objectives and the physical therapist's focus on their lifting strategy may have additionally influenced their movement behavior.

Potential implications

The findings suggest that fear-driven protective movement strategies vary by occupation, highlighting the need for further research to explore the clinical implications of these differences in preventing and managing LBP. Although the results support existing evidence suggesting potential adverse associations between psychological factors and lifting kinematics, longitudinal studies are needed to determine whether these movement adaptations indeed reflect protective strategies with negative long-term consequences. Considering the biopsychosocial contributors to LBP[56], it would be of particular interest to investigate whether these psychomotor interactions are associated with an increased risk of LBP in healthy, pain-free individuals. Additionally, the high levels of lifting-

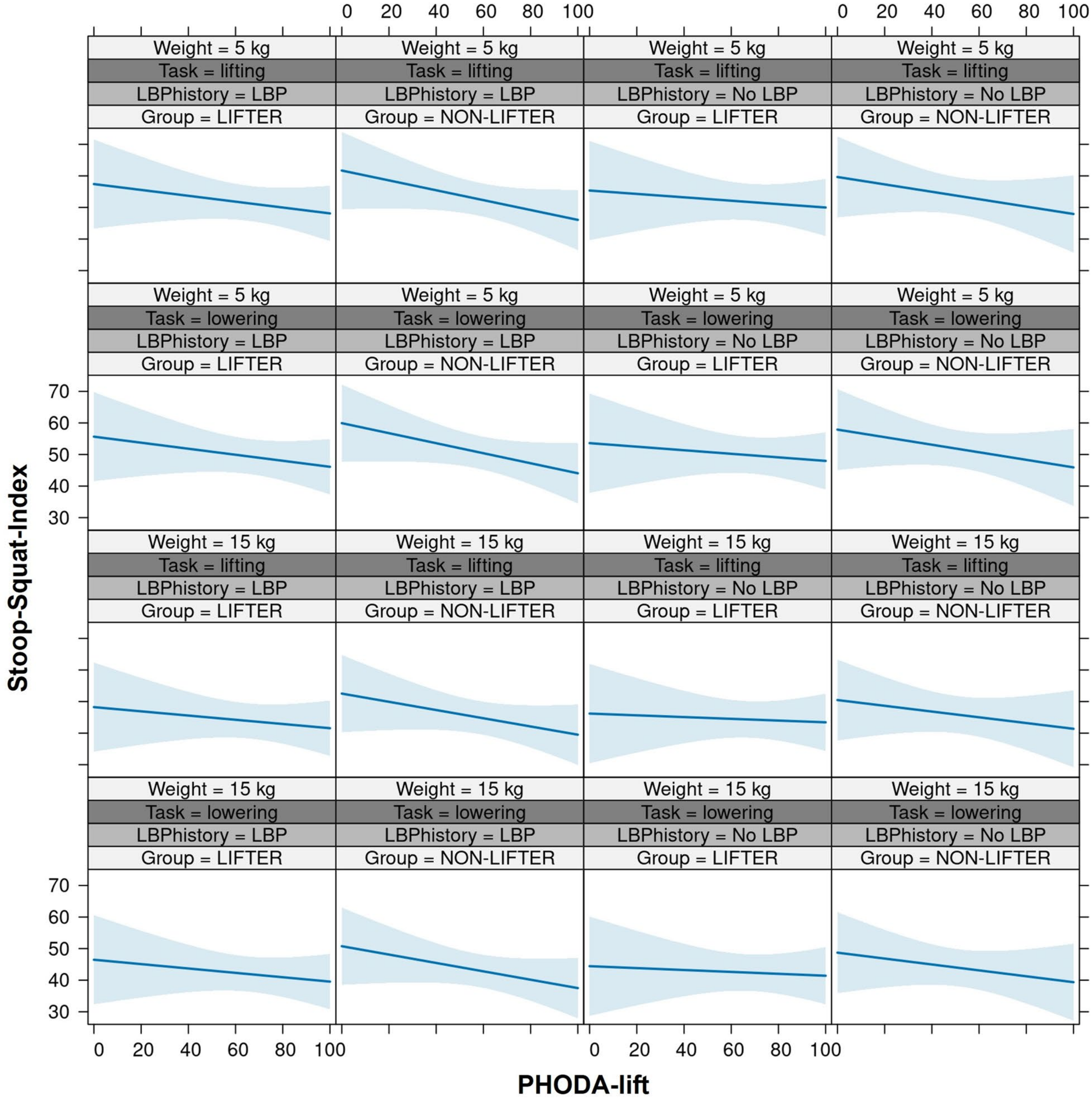

Fig. 2. Predictor effect plot illustrating the effect of PHODA-lift (x-axis) on the Stoop-Squat-Index (y-axis), across different subgroups defined by all combinations of Group (LIFTER or NON-LIFTER), Task (lifting or lowering), Weight (5 kg or 15 kg), and LBP history (LBP or No LBP). Columns are sorted by LBP history and Group, and rows by Weight and Task. Model-based predictions for the Stoop-Squat-Index are shown as blue solid lines, with 95% confidence intervals represented by blue shaded areas.

specific pain-related fear in LIFTER warrant reconsideration of current lifting behavior recommendations in manual handling training. Since elevated pain-related fear is associated with an increased risk of LBP[15–17], such interventions should aim at reducing negative back beliefs rather than reinforcing overly cautious movement patterns.

Conclusion

This study demonstrates that the effect of task-specific pain-related fear on lifting kinematics varies by occupation. A fear-driven reduction in lumbar spine ROM was observed in individuals without repetitive lifting tasks at work, but not in those with such tasks. These protective movement strategies were more pronounced when lowering heavier loads, suggesting increased caution in response to higher perceived risk. Further research is needed to determine the clinical relevance of these findings by exploring potential causal relationships between pain-related fear, lifting behavior, and the development or persistence of LBP.

Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Received: 27 March 2025; Accepted: 16 October 2025
Published online: 20 November 2025

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Acknowledgements

We thank the Swiss Physiotherapy Association (Physioswiss) for financial support, and Swiss Post for assistance in the recruitment of study participants. In addition, the authors thank Liliane Kümmerli, Vanessa Leuthard, Philippe Hinzer, Manuel Wandeler, Aron Krähenbühl, Lara Seewer, and Jasmin Zurbriggen for their assistance in data processing.

Author contributions

C.B. contributed to the conception and design of the study, the acquisition, analysis and interpretation of data, and wrote the original draft of the manuscript. O.F., M.M., and C.H. contributed to the conception and design of the study and the interpretation of data. D.W. contributed to the acquisition and analysis of data. A.M. contributed to the analysis and interpretation of data. S.S. contributed to the conception and design of the study, the interpretation of data and supervised the work. All authors reviewed the manuscript and approved the version to be published.

Declarations

Competing interests

The authors declare no competing interests.

Additional information

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1038/s41598-025-24890-z.

Correspondence and requests for materials should be addressed to C.B.