The Association of Fear of Movement and Postural Sway in People with Low Back Pain

Anita Meinke¹, Cinzia Maschio², Michael Meier³, Walter Karlen¹,⁴*, Jaap Swanenburg³,⁵‡

¹Mobile Health Systems Lab, Department of Health Sciences and Technology, ETH Zurich, Zurich, Switzerland
²Institute for Regenerative Medicine, University of Zurich, Zurich, Switzerland
³Integrative Spinal Research, Department of Chiropractic Medicine, Balgrist University Hospital, Zurich, Switzerland
⁴Institute of Biomedical Engineering, University of Ulm, Ulm, Germany
⁵Directorate of Research and Education, Physiotherapy Occupational Therapy Research Center, University Hospital Zurich, Zurich, Switzerland

‡These authors contributed equally to this work and share senior authorship

* Correspondence:
Corresponding Author
walter.karlen@ieee.org

Keywords:
fear of movement, kinesiophobia, postural control, postural sway, low back pain, anatomical planes, bipedal stance.
Abstract

**Background:** Fear of movement is thought to interfere with the recovery from low back pain (LBP). To date, the relationship between fears and movement characteristics such as balance has not been adequately elucidated. Recent findings suggest that more specific fears need to be assessed and put in relation to a specific movement task. We propose that the fear to move the trunk in a certain direction is distinctly related to the amount of postural sway in different directions. Therefore, our aim was to investigate whether fear of movement in general and on a certain movement plane is related to postural sway.

**Methods:** Data was collected from participants with LBP during two assessments approximately three weeks apart. Postural sway was measured with a force-platform during quiet standing with the eyes closed. Fear of movement was assessed with an abbreviated version of the Tampa Scale of Kinesiophobia (TSK-11) and custom items referring to fear from trunk movements on the sagittal and the frontal plane.

**Results:** Based on data from 25 participants, fear of movement on the frontal plane was positively related to displacement on the sagittal and frontal plane and to velocity on the frontal plane (P=.04; P=.004; P=.002). Fear of movement on the sagittal plane was not associated with any direction specific measure of sway. A positive relation of the TSK-11 with velocity of the frontal plane (P=.008) was found, but no association with undirected measures of sway.

**Discussion:** Fear of movement in the frontal plane may be especially relevant to postural sway under the investigated stance conditions. It is possible that fear of moving in the frontal plane could interfere with balance control at the hip, shifting the weight from side to side on the frontal plane to control balance.

**Conclusion:** For the first time the directional relationship of fear of movement and postural sway was studied by investigating the postural sway with a force-platform. Fear of movement on the frontal plane was positively associated with several measures of postural sway.
1 Introduction

The estimates of “disability” for low back pain (LBP) generated within the global burden of disease study are larger than for any other complaint (Wu et al., 2020). Furthermore, a relationship between disability assessed by questionnaires and fear in people with LBP (Costa et al., 2011; Carvalho et al., 2017; Nordstoga et al., 2019) or other similar pain conditions (Luque-Suarez et al., 2019) is often observed. These connections highlight the need to understand the involvement and consequences of fear for people with LBP.

For many years, fears were suspected to lead to adverse outcomes in people with LBP (Vlaeyen and Crombez, 1999). The basic premise of this line of work is that people who respond to pain with fear and withdrawal from activities regarded as potentially harmful, could lose the benefits of physical activity and movement, and thus might consolidate their pain even further (Vlaeyen and Crombez, 1999). Indeed, a review showed that stronger fears during subacute LBP may promote difficulties to return to the office (Wertli et al., 2014). However, not all data available are in line with this model (Pincus et al., 2010; Costa et al., 2011). For example, Carvalho et al. (2017) did not observe a reduction in physical activity with increased fear. On the other hand, LBP is linked to movement behavior and while it is assumed that these altered movements may serve to avoid physical stress on the spine or surrounding tissues, they could possibly cause additional stress (van Dieën et al., 2019).

For example, a protective movement behavior (i.e., stiffening the spine) might be associated with increased muscle co-contraction, potentially causing additional load on spinal structures (van Dieën et al., 2019). This additional stress may jeopardize back health (van Dieën et al., 2019). Van Dieën et al. (2019) further remarked that such reactions could be purely detrimental without any advantage for the person if they are provoked by unjustified fears.

An association between fear of movement and the tendency to move the torso in a stiff manner is discussed in the scientific literature (Karayannis et al., 2013; Alsubaie et al., 2021; Christe et al., 2021). Recently, a meta-analysis found that people with LBP and greater fear may slightly restrain their movement of the spine (Christe et al., 2021). Karayannis et al. (2013) found a higher rigidity in reaction to perturbations of the torso, and flexion on the sagittal plane occurs more slowly when fear of movement is elevated (Nordstoga et al., 2019; Osumi et al., 2019). Furthermore, people with greater fear and LBP may be more imprecise in tracing a requested movement trajectory by flexing and extending their torso (Alsubaie et al., 2021).

Assessments of postural balance are commonly used in studies investigating LBP. “Balance is a generic term describing the dynamics of body posture to prevent falling” (Winter, 1995, 194) and the
operation of the sensorimotor system regulating balance can be observed by describing the pathway of the vertical ground reaction force, also known as center of pressure (COP) (Winter, 1995). Although this is strictly speaking not accurate, as COP based parameters describe the motor activity generated to steer the body’s sway and not the actual movement of the center of mass (Winter, 1995). For consistency with other publications, we will discuss COP-based parameters as a proxy measure of body sway. Several reviews have summarized research results on sway in people with LBP (Ruhe et al., 2011; Mazaheri et al., 2013; Berenshteyn et al., 2019; Koch and Hänsel, 2019). Three of these reviews highlighted the enlarged sway parameters found in people with LBP (Ruhe et al., 2011; Berenshteyn et al., 2019); specifically when contributions from the visual sense were removed (Koch and Hänsel, 2019). While another review emphasized that the opposite was the case for a subset of studies where a reduction in sway was found (Mazaheri et al., 2013). Further investigations of the impact of fear on sway assessments was suggested (Mazaheri et al., 2013; Berenshteyn et al., 2019) and that this heterogeneity in study results could arise from counteracting mechanisms of fear and other mechanisms associated with pain which are thought to increase sway (Mazaheri et al., 2013). Kiers et al. (2015) proposed that fear opposes the effect of pain by increasing stiffness.

Mazaheri et al. (2014) evaluated the assumptions of counteracting mechanisms in another study and inferred from their findings that fear did not impact sway. However, the association of fear and sway was not directly analyzed (Mazaheri et al., 2014). Instead, the inference was made by comparison of a group of people who had just overcome LBP (as fear was not diminished in this group yet), to people with ongoing and without LBP (Mazaheri et al., 2014). In addition, other studies have reported data on the influence of fear on postural sway or other balance measures in people with LBP (Sung et al., 2015; Jacobs et al., 2016; Shanbehzadeh et al., 2018; Hlaing et al., 2020; Zhang et al., 2020; Mikkonen et al., 2022). Shanbehzadeh et al. (2018) found that participants with greater fear showed decreased postural sway across multiple conditions including manipulations of vision, proprioception, and cognition. Kahraman et al. (2018) found a positive association with a measure combining sway across different manipulations of sensory input while standing quietly in male, but not in female participants or for any of the individual conditions. In their study, fear was negatively associated with some limits of stability measures, but they found no association with fear for sway measures in single legged stance (Kahraman et al., 2018). Only recently Mikkonen et al. (2022) presented results from a larger group of participants, who were assessed under different conditions in narrow, bipedal stance and several small but significant positive correlations of fear and postural sway area were reported. However, these associations were not found for postural sway velocity, for which age alone was a significant predictor in a model including additional variables (Mikkonen et al., 2022). The authors concluded that there was no effect of fear on postural sway.
Meinke et al. The Association of Fear of Movement and Postural Sway in People with Low Back Pain

(Mikkonen et al., 2022). Hlaing et al. (2020) did not find a relation of fear with the time participants could maintain single leg stance on firm ground but observed a negative association on compliant ground. In a cohort of people who had not yet developed chronic LBP and who displayed reduced motor control capabilities during movement assessments, balance during sitting on a platform that was only supported in the center was not found to correlate with fear (Sung et al., 2015). Another study that investigated how much the body shifted when reacting to tilts of the supporting ground, showed a positive relation with fear (Jacobs et al., 2016). In addition to fear, catastrophic thoughts in people with chronic LBP appear to be also linked to sway, although the direction of this effect was reported inconsistently (Zhang et al., 2020). Thus, while there is some first evidence on the relationship between fear and postural sway, the current evidence appears difficult to reconcile; possibly due to methodological variations between studies.

It has been argued that commonly used comprehensive assessments of fear do not capture the selectivity of fears to perform distinct movements (Leeuw et al., 2007) and thus make it harder to detect associations of fear with the respective movement characteristics (Pincus et al., 2010; Matheve et al., 2019). Indeed, Matheve et al. (2019) only identified a negative association with movement in the lumbar region during lifting with a measure directly quantifying fear of lifting, but not with common fear assessment tools. Further research confirmed analogous findings in people without pain (Knechtle et al., 2021) and by referring to such results, other researchers emphasized that more targeted assessments should be used (Christe et al., 2021). This argument is contradicted by the results of a study by Karayannis et al. (2013) who found that common assessments of fear were linked to rigidity of the torso, but not to an item that was designed to capture fear of the task used for the rigidity assessment. Nevertheless, the use of more specific measures of fear may be relevant to the clarification of the relationship between fear of movement and postural sway.

While postural sway is often described by using separate parameters for the frontal and the sagittal plane, as for example in the study of Mazaheri et al. (2014), fear is usually assessed in a more general format and no distinction between movement planes is made. Although the Photograph Series of Daily Activities-Short Electronic Version (PHODA-SEV) was designed to comprise of movement examples for different planes, the resulting score does not distinguish between these planes (Leeuw et al., 2007). Some people may have greater fear from movements on one plane than from movements on the other plane, which could have distinct effects on postural sway. Direction specific fears might result, for example, in a restriction of sway in the movement plane corresponding to the fear. Therefore, we assumed that fears from spinal flexion in different directions might relate differently to postural sway along different planes.
To gain further insights into the relationship between fear of movement and postural sway we conducted secondary analyses of COP data obtained from people with LBP who participated in a clinical trial that investigated the effect of an exercise intervention (Meinke et al., 2022). Our aim was to investigate whether postural sway, described by mean displacement and velocity, is affected by fear of movement in general, and whether fear of movements on different planes affect sway for the corresponding movement directions.

2 Materials and methods

2.1 Study design and participants

We describe secondary analyses of data from a randomized controlled trial which investigated the effects of an exergame for people with LBP on postural sway (Meinke et al., 2021, 2022). Data of two baseline assessments taken about 3 weeks apart were used. Participants had not yet been randomized or received any intervention at the time the data were captured. The prospective study participants were contacted using leaflets, online advertisement, and personal interaction. Participants were included if they had back pain in the lower region, were above 18 years old, not in any therapies for LBP for the past half year before study participation and gave their informed consent. Participants were excluded from the study due to radicular symptoms or other specific causes of LBP, pain perceived as too strong or vision too low to use the exergame, pharmacological treatment that negatively influences sway, allergies to the band used to adhere sensors to the skin, pregnant women, or language barriers. Ethical approval was received from the Cantonal Ethics Committee Zurich, Switzerland (BASEC-2018-02132).

2.2 Procedures

Fear of movement, postural sway and pain intensity data was collected at both assessments. A numeric rating scale (0-10) was used to query pain intensity during the past 7 days (Chiarotto et al., 2018). Weight and height were determined at the first assessment. Fear of movement was quantified among other variables using an online form through RedCap (Harris et al., 2009). All participants used the same computer monitor to take the survey before the postural sway assessments were carried out. The questions were either presented in German or English.

2.3 Fear of movement

For a generic score of fear of movement, the abbreviated version of the Tampa scale for Kinesiophobia (TSK-11) was adopted (Woby et al., 2005; Rusu et al., 2014). The English assessment shows a good
psychometric quality, which was comparable to the full scale in patients with chronic LBP (Woby et al., 2005). The German TSK-11 has been validated and shows sufficient internal consistency (Rusu et al., 2014). Direction specific items of fear (in the following referred to as directional fear) were included later during the study, therefore data from fewer participants were available. For this directional fear assessment, a custom question type was used. Earlier studies, which had integrated fear assessments more directly related to the movements under investigation, appended further items to the PHODA-SEV (Karayannis et al., 2013) or used items already available within the PHODA-SEV (Matheve et al., 2019; Knechtle et al., 2021). Similar to the style of the PHODA-SEV, we asked participants to rate their fear of movements of the torso in different directions (Figure 1). As the PHODA-SEV requires the participants to put photographs in order depicting different movements, we added icons to clarify the movement referenced in the questions. The fear assessment for the sagittal plane was defined as the mean of two items referring to flexion and extension movements. A measure to quantify whether the participants judged fear on the frontal plane or sagittal plane trunk movement as higher was introduced and is hereinafter referred to as relative directional fear. Relative directional fear was calculated by subtracting the fear rating for the frontal plane from the fear rating of the sagittal plane. Negative values describe higher fear ratings for the frontal plane movement, while positive values describe relatively stronger fears in the sagittal direction. Values close to zero indicate no difference in fear ratings between frontal and sagittal plane movements.

![Figure 1: Question format used for the assessment of directional fear.](image-url)
2.4 Assessment of postural sway

The assessments of postural sway were implemented considering the suggestions from Ruhe et al. (2010) and were performed for 120 seconds in 4 consecutive repetitions. COP data was acquired from a pressure plate (AMTI, Accusway Plus, Watertown, MA, USA). The participants maintained still, upright stance and had their hands loosely hanging, closed their eyes during the assessments, and wore a shaded ski goggles. The exact stance position of the participants was outlined on a synthetic sheet to replicate the stance throughout all subsequent recordings. Prior to the standing task and after task completion, participants performed a movement leaning to both sides, which was intended for combining the recordings with data from other sensors that were not relevant for the analyses presented here. This movement was removed including the 5 seconds after and before the movement respectively. Thus, of each trial only 110 seconds were analyzed. After filtering the COP recordings with a low-pass fourth order Butterworth filter (10 Hz cut-off frequency) and centering the data, displacement from the center, velocity and their directional versions were calculated according to Prieto et al. (1996) (equation 1-5, 8-11). General displacement was calculated by averaging the distances of each data point from the center of the trajectory. In an analogous way, displacement for the sagittal and frontal plane were calculated by averaging the absolute values of the x or y coordinates of each point in the trajectory. General velocity was calculated as the path length traveled divided by time, and velocities for the sagittal and frontal plane were calculated by the path traveled on the respective axis divided by time. These preparatory steps were performed using MATLAB R2018a (The MathWorks Inc., Natick, MA, USA). Averages across the 4 trials were used for data analysis.

2.5 Statistical methods

For hypothesis testing, we used mixed effects linear models. R (R Core Team, 2021) version 4.04 and the package lme4 (Bates et al., 2015) were used for the statistical analysis. Continuous predictors including pain scores and fear assessments were standardized across the entire sample before inclusion into the models. Normal distribution of the residuals and random intercepts were assessed using normal-qq plots and the presence of heteroscedasticity was reviewed by plotting the predicted values against the residuals. The residuals were further plotted against each predictor variable individually. These analyses were performed for the untransformed, log(x+1), square root transformed and reciprocally transformed data. Based on the residual analysis the models with log transformed outcomes were chosen. For each postural sway outcome, we estimated a first model to assess the effect of potential confounding factors (assessment visit, sex, age, height, weight and pain). Based on the results of this analysis of confounding factors, we included the variables visit, age and weight as
fixed effects in the baseline models for all sway outcomes. Effects of the fear variables were tested by adding each individual variable of interest to the baseline model and comparing the resulting model against the baseline model only. All models included the participants as random effect. The influence of every participant on the models was assessed using cook’s distance calculated using the R package Influence.ME (Nieuwenhuis et al., 2012). Each participant classified as influential in the initial model was separately removed from the models and comparisons were reevaluated to see if individual participants affected the statistical significance of the results. Reliability of fear assessments was estimated using ICC model (2,1), relying on the ANOVA results as implemented in the package psych (Revelle, 2021) and interpreted according to the reliability thresholds proposed by Portney and Watkins (1993). Reliability estimates were based on data from participants who completed the questionnaires at both assessment visits. For one participant the values for directional fear were missing and thus imputed with the value of 50, representing the default slider position. Replacements were made as we assumed an agreement with the default slider position (not producing an output value if the slider was not clicked) was more plausible, than the participant having overlooked these questions.

3 Results

3.1 Participant characteristics

Thirty-two participants completed the first, and 27 participants completed the second visit, adding up to a total of 59 observations of postural sway and general fear. As the directional questions had been introduced after an amendment to the study protocol, the data used for the directional analysis originates from 25 unique participants, who contributed to 41 observations. Sixteen participants contributed directional fear data both for visit 1 and 2. Demographic characteristics, fear of movement, and postural sway estimates are summarized in Table 1. Oftentimes, ratings of fear on the frontal and on the sagittal plane were similar, as depicted in Figure 2A, where many values are close to the diagonal line. Participants reporting relatively higher fear on the sagittal plane showed rather low values for both directions (Figure 2A, dashed triangle). Relative directional fear was calculated by subtraction of fear on the frontal plane from fear on the sagittal plane, resulting in a distribution including many values close to zero (Figure 2B). Negative values indicated higher fear on the frontal plane whereas positive values show that fear was rated higher for the sagittal plane. Estimates of intra-class-correlation (ICC) coefficients for directional fear variables were in the range from moderate to good, although some of the confidence intervals included values of below 0.5 and we could not exclude poor reliability for these cases (Table 2).
Figure 2: Relative directional fear is calculated by subtracting fear ratings for the frontal plane from fear ratings of the sagittal plane. Background in red shade indicates higher fear values for the frontal plane, grey shade background shows area of higher fear on the sagittal plane. **(A)** Ratings of fear on the sagittal and the frontal plane. The dashed triangle highlights that participants who rated fear on the sagittal plane higher than fear on the frontal plane showed low to medium values on both planes. **(B)** Distribution of relative directional fear. Negative values for relative directional fear show higher fear of frontal plane movements and positive values show higher fear of sagittal plane movements.
Table 1. Descriptive statistics of participant characteristics, fear assessments and postural sway outcomes at both assessment visits.

| Variable                      | Visit 1       | Visit 2       |
|-------------------------------|---------------|---------------|
|                               | Median (IQR)/ M (SD) | Median (IQR)/ M (SD) |
| Participant characteristics    |               |               |
| N                             | 32c           | 27c           |
| Age                           | 37.50 (24.75) | 35.00 (25.5)  |
| Height                        | 171.26 (7.92) | 172.05 (7.65) |
| Sex (male/female)             | 11/21c        | 10/17c        |
| Language (English/German)     | 6/26c         | 5/22c         |
| Pain Intensity                | 3.19 (1.47) b | 2.59 (1.34) b |
| General Fear                  |               |               |
| TSK-11                        | 19.59 (4.41) b | 19.96 (5.62) b |
| Displacement (mm)             | 4.82 (1.71)   | 5.24 (2.13)   |
| Velocity (mm/s)               | 9.76 (4.11)   | 11.15 (4.42)  |
| Directional Fear              |               |               |
| n                             | 20c           | 21c           |
| Fear flexion                  | 23.00 (50)    | 18.00 (26)    |
| Fear extension                | 31.50 (49.5)  | 17.00 (49)    |
| Fear sagittal                 | 32.00 (46.75) | 18.50 (39.5)  |
| Fear frontal                  | 25.00 (47.5)  | 17.00 (25)    |
| Relative directional fear     | 0.00 (6.25)   | 0.00 (17.5)   |
| Displacement sagittal (mm)    | 4.14 (1.71)   | 4.22 (1.90)   |
| Displacement frontal (mm)     | 1.88 (1.53)   | 2.54 (1.35)   |
| Velocity sagittal (mm/s)      | 7.86 (4.24)   | 9.36 (4.04)   |
| Velocity frontal (mm/s)       | 4.48 (1.95)   | 3.77 (2.60)   |

\[ a \] Median (IQR): Median (inter quartile range).

\[ b \] M (SD): Mean (standard deviation).

\[ c \] Count: Counted data.
Table 2. Reliability estimates for directional fear questions (n=16).

| Variable          | Intraclass Correlation Coefficient Estimate (95% CI) |
|-------------------|------------------------------------------------------|
| Fear flexion      | 0.75 (0.56 to 0.87)                                  |
| Fear extension    | 0.57 (0.31 to 0.76)                                  |
| Fear sagittal     | 0.68 (0.38 to 0.86)                                  |
| Fear frontal      | 0.74 (0.47 to 0.89)                                  |
| Relative directional fear | 0.84 (0.66 to 0.93)                                |

3.2 Effect of fear of movement on postural sway

The assessment of confounding factors in baseline models resulted in assessment occasion, age and weight to be included in the baseline models for all outcomes (Table 3). Comparisons of the baseline models including the fear predictor of interest to the baseline model alone are reported in Table 4. General fear as measured by the TSK-11 was not associated with general mean displacement and velocity. However, for the directional sway measures, an association was found with velocity of sway on the frontal plane. The fear assessment for the sagittal plane was not associated with any of the directional sway measures. The fear assessment for the frontal plane was associated with displacement and velocity in the frontal plane, but also with displacement on the sagittal plane. The predictor relative directional fear showed the same pattern of associations.

We tested whether removing individual participants that had been identified as influential by using cook's distance would have changed the results of the model comparisons. For two cases, when either of these participants would be removed, the effect of fear on the frontal plane on displacement in the sagittal plane was no longer significant (both with \( p = .05 \)) In addition, the effect of the TSK-11
on displacement in the frontal plane could have become statistically significant by removing one influential case.

Graphical representations (Figures 3A-H and 4A-H) of the untransformed directional data showed that displacement and velocity both tended to be higher with higher fears. The negative correlations observed for relative directional fear showed that relatively higher fear of frontal plane movements was associated with higher displacement in both directions.

Graphical inspection revealed that of the movements comprising the measure for fear of the sagittal plane, flexion and extension, flexion considered separately may have a positive association with velocity measures (Supplementary file 1). Therefore, additional model comparisons for flexion and extension were conducted. Neither flexion nor extension on the sagittal plane had a statistically significant effect on any of the directional postural sway outcomes.

Figure 3: Postural sway displacement and fear variables. Association of postural sway displacement on the sagittal plane and (A) general fear, (B) fear of sagittal plane movement, (C) fear of frontal plane movement, (D) relative directional fear. Association of postural sway displacement on the frontal plane and (E) general fear, (F) fear of sagittal plane movement, (G) fear of frontal plane movement, (H) relative directional fear. R values are spearman correlation coefficients. Negative values for relative directional fear show higher fear of frontal plane movements and positive values show higher

PREPRINT
fear of sagittal plane movements. Data from assessment visit T1 is shown in blue and data from T2 in orange. Data from participants who changed the analysis results when removed from the corresponding mixed model analysis is highlighted within a grey circle.

![Figure 4: Postural sway velocity and fear.](image-url)

Figure 4: Postural sway velocity and fear. Association of postural sway velocity on the sagittal plane and (A) general fear, (B) fear of sagittal plane movement, (C) fear of frontal plane movement, (D) relative directional fear. Association of postural sway velocity on the frontal plane and (E) general fear, (F) fear of sagittal plane movement, (G) fear of frontal plane movement, (H) relative directional fear. R values are spearman correlation coefficients. Negative values for relative directional fear show higher fear of frontal plane movements and positive values show higher fear of sagittal plane movements. Data from assessment visit T1 is shown in blue and data from T2 in orange.
Table 3. Models assessing the influence of confounding variables and baseline models only including the predictors selected as relevant.

| Predictor | Outcomes | Displacement | Velocity | Displacement | Velocity |
|-----------|----------|--------------|----------|--------------|----------|
|           |          | Sagittal     | Frontal  | Sagittal     | Frontal  |
| n comparison | 32 | 32 | 25 | 25 | 25 | 25 |

Potential Confounders

|     | Displacement | Velocity | Displacement | Velocity |
|-----|--------------|----------|--------------|----------|
|     | Sagittal     | Frontal  | Sagittal     | Frontal  |
| Visit | 0.07 (-0.00 to 0.13) | 0.04 (-0.02 to 0.10) | 0.03 (-0.07 to 0.11) | 0.16 (0.05 to 0.27) | 0.07 (-0.01 to 0.15) | 0.06 (-0.02 to 0.14) |
| Sex  | 0.04 (-0.19 to 0.27) | -0.02 (-0.21 to 0.17) | 0.07 (-0.13 to 0.26) | 0.14 (-0.14 to 0.43) | -0.14 (-0.19 to 0.22) | 0.05 (-0.18 to 0.29) |
| Age  | 0.01 (-0.08 to 0.10) | 0.08 (0.01 to 0.16) | -0.05 (-0.13 to 0.03) | 0.09 (-0.03 to 0.21) | -0.03 (-0.09 to 0.17) | 0.04 (-0.06 to 0.13) |
| Height | 0.04 (-0.08 to 0.15) | 0.03 (-0.07 to 0.12) | -0.07 (-0.18 to 0.03) | -0.02 (-0.17 to 0.13) | -0.02 (-0.12 to 0.09) | -0.03 (-0.15 to 0.09) |
| Predictor   | Estimate | (95% CI) |
|------------|----------|----------|
| Weight     | -0.05    | (-0.14 to 0.13) |
|            | -0.05    | (-0.02 to 0.04) |
|            | -0.01    | (-0.05 to 0.13) |
|            | -0.01    | (-0.14 to 0.12) |
|            | 0.09     | (-0.00 to 0.19) |
|            | 0.08     | (-0.02 to 0.19) |
| Pain Intensity | 0.02  | (-0.03 to 0.07) |
|            | -0.00    | (-0.06 to 0.05) |
|            | 0.04     | (-0.03 to 0.11) |
|            | -0.05    | (-0.03 to 0.06) |
| Baseline Model | 0.06  | (-0.01 to 0.12) |
| Visit      | 0.03     | (-0.02 to 0.09) |
|            | 0.03     | (-0.06 to 0.11) |
|            | 0.13     | (0.03 to 0.24) |
|            | 0.07     | (-0.01 to 0.14) |
|            | 0.04     | (-0.04 to 0.12) |
| Age        | 0.01     | (-0.08 to 0.08) |
|            | -0.04    | (-0.13 to 0.04) |
|            | 0.10     | (-0.02 to 0.22) |
|            | 0.05     | (-0.05 to 0.14) |
| Weight     | -0.04    | (-0.13 to 0.13) |
|            | -0.01    | (-0.01 to 0.10) |
|            | -0.03    | (-0.09 to 0.11) |
|            | -0.00    | (-0.16 to 0.18) |
|            | 0.07     | (-0.03 to 0.18) |

3 Estimate and (95% CI).

4 All estimates are based on log transformed outcome variables. Continuous predictors (including pain intensity) were standardized before analysis. Statistically significant results are in bold type.

5
Table 4. Comparisons between the baseline model and the baseline model including an additional fear predictor variable.

| Predictor       | Outcomes | Displacement Velocity | Displacement Velocity |
|-----------------|----------|-----------------------|-----------------------|
|                 |          | Sagittal P            | Frontal P             |
|                 |          | Sagittal P            | Frontal P             |
|                 |          | Chi² P                |                      |
|                 |          | Chi² P                |                      |
| n comparison    | 32       | 32                    | 25                    | 25                    | 25                    | 25                    |
| TSK-11<sup>a</sup> | 0.99     | 0.32                  | 0.90                  | 0.34                  | 0.66                  | 0.42                  | 3.13                  | 0.08                  | 1.17                  | 0.28                  | 7.14                  | 0.008                 |
| Fear sagittal   | 0.35     | 0.55                  | 0.26                  | 0.61                  | 0.31                  | 0.58                  | 1.27                  | 0.26                  |
| Fear frontal    | 4.35     | 0.04                  | 8.15                  | 0.004                 | 0.93                  | 0.34                  | 9.79                  | 0.002                 |
| Rel. direct.    | 9.47     | 0.002                 | 8.02                  | 0.005                 | 0.39                  | 0.53                  | 7.07                  | 0.008                 |

<sup>a</sup> TSK-11: Tampa Scale of Kinesiophobia – 11 Item version.

Comparisons of the baseline model against the baseline model and an additional predictor describing fear. Log transformed models. Continuous predictors (including pain intensity) were standardized before analysis. Statistically significant results are indicated in bold type.
4 Discussion

4.1 Summary of main findings

We conducted analyses on the association of fear and postural sway considering fear of movement in general and fear of performing trunk movements on different planes. Our analyses revealed that the TSK-11 as a measure of general movement related fear was not associated with undirected measures of sway but was related to velocity on the frontal plane. Other than expected, fear scores measured for individual planes were not more closely associated with sway measures for the corresponding plane. Instead, fear of movement on the sagittal plane was not associated with any directional outcome, but fear measured for the frontal plane was associated with multiple directional measures. Sway parameters tended to increase rather than decrease with elevated fear.

4.2 Association of fear of movement and postural sway

It had been proposed that assessments of fear should be based on concrete movement examples rather than broader assessments (Leeuw et al., 2007) and that assessments of fear that are matched more precisely to the movement task used might be better suited to detect associations with movement quality (Pincus et al., 2010; Matheve et al., 2019). Our results support this notion only partially, as we observed a significant association between TSK-11 scores association and sway velocity on the frontal plane. On the other hand, as we detected more associations of directional fear questions with sway outcomes, the question format encouraging participants to think of specific movements could have contributed to making an association between fear and sway more visible.

The results of the directional analysis show that fear of movement in the frontal plane, but not fear of movement in the sagittal plane was associated with postural sway in people with LBP. A potential explanation of these results may be derived from the basic mechanisms at work during bipedal stance. During regular standing with approximately parallel feet on stable ground, two basic mechanisms have been suggested as central to regulating postural sway (Winter, 1995). Balance control on the frontal plane should rely on muscle contractions at the level of the pelvis, moving the body weight laterally, whereas sway on the sagittal plane is regulated predominantly by contractions at the level of the ankle (Winter, 1995). Fear of frontal plane movements might thus interfere with the use of this lateral weight shifting of the hip. By contrast, no movement of the torso or the hip in the sagittal plane should be required for regulating balance under these basic stance conditions. Therefore, fear of moving the torso on the sagittal plane might cause less interference with balance under the investigated conditions. The results of a study of Mok et al. (2004) suggested that people with LBP could rely less
on their hip for regulating sway and further remarked that fear might be a factor related to limiting the use of the hip. Nonetheless, in their study a reduction in velocity and a descriptive tendency towards increased range on the sagittal plane in some conditions was observed in people with LBP (Mok et al., 2004). To note, this work did not focus on testing the assumption that the observed pattern of results might be caused by mechanisms involving the hip and future studies are required.

4.3 Direction of the association between fear and postural sway

The data obtained in this study suggests that elevated fear leads to an increase in sway parameters. It could be argued that people with LBP and high fear refrain from using an effective mechanism for balance regulation (i.e., the lateral weight shifting described above) which could compromise balance and lead to an increase in sway. This argumentation is similar to the view presented in the review of Koch and Hänsel (2019), stating that postural sway is increased under more challenging conditions in people with LBP, potentially because the hip strategy required for managing these conditions could be impaired. In contrast, others have argued that elevated fear might be linked to a decrease of sway parameters (Mazaheri et al., 2013, 2014; Kiers et al., 2015). This assumption of decreased sway is supported by empirical data from a study of Shanbehzadeh et al. (2018) which suggests less sway in people with elevated fear in comparison with people with lower fear. Methodological factors that differ from the approach used in our study include the categorization of participants with low and high fear based on the Pain Anxiety Symptom Scale-20, the standing condition with the feet positioned directly next to each other and the use of multiple assessment conditions including for example dual task assessments (Shanbehzadeh et al., 2018). These aspects may have played a role causing the differences between the observed results. Other researchers who assessed the association of fear variables and postural sway under bipedal stance conditions without platform perturbations obtained deviating results (Mazaheri et al., 2014; Kahraman et al., 2018; Zhang et al., 2020; Mikkonen et al., 2022). Mazaheri et al. (2014) concluded that fear did have little effect but did not report the association of sway and fear directly. Instead, they relied on comparisons between groups of people with LBP, people who just recovered and healthy participants to infer the effect of fear, based on the differences in pain and fear status of these groups (Mazaheri et al., 2014). Mikkonen et al. (2022) arrived at the same conclusion, that fear did not have an effect, but nevertheless had reported several positive correlations of fear with sway area measures. Kahraman et al. (2018) found an increase in sway only for male participants for a score combining assessments from several conditions, but otherwise found no significant correlations in several investigated conditions. Zhang et al. (2020) supposedly found larger sway for participants with higher catastrophic thoughts, but the direction of the detected association was not reported consistently throughout the manuscript. Thus, our study complements
this existing literature with an estimate for a tendency towards increased sway with higher fear. The opposing findings in the currently available literature could be caused by the different fear concepts and their operationalizations, as well as variations in stance positions.

4.4 Relative directional fear and postural sway

Values for relative directional fear were closely centered around zero as many participants did not judge one movement direction as more harmful than the other. This suggests that the direction of movement with respect to fear seems to be only relevant for a smaller number of people. As a tendency, negative values (higher fear on the frontal plane) were associated with higher sway, while positive values (higher fear on the sagittal plane) were associated with less sway. As indicated in Figure 2 A, in this study, participants with higher values on the sagittal plane tended to have lower fear values for both planes, than participants with higher fear on the frontal plane. This could have influenced the results for relative directional fear, as in this data set relative directional fear was conflated to some degree with the general tendency to rate fear as higher or lower. Therefore, and as the number of participants who produced values other than zero for relative directional fear was low, these analyses should be repeated based on other datasets to draw further conclusions.

4.5 Strengths and Limitations

Several methodological aspects must be considered when interpreting the current results. The data originated from study participants with LBP who registered for a trial investigating an exercising intervention. Therefore, a selection bias might be present. For example, only participants with lower levels of fear may have registered for the trial and the results need to be interpreted in the context of this subset. Furthermore, to assess the directional fear, we introduced custom questions that did not originate from a validated questionnaire. The ICC estimates calculated for these questions indicated moderate to good reliability. Nevertheless, these estimates were derived from a smaller number of participants and thus had broader confidence intervals which could partially not exclude poor reliability values. In addition, it remains unclear whether it was adequate to use the mean of the flexion and extension question as a measure for fear of movements in the sagittal plane. In a recent fear learning experiment, fear of extension of the spine was rated higher than fear of flexion, but the images showed a more extreme extension movement than it was depicted in this study (Gatzounis et al., 2021). Visual inspection of our data indicated that there may be an association of postural sway velocity with flexion movements, but not extension (Supplementary File 1). Future studies may therefore need to consider flexion and extension in the sagittal plane separately. However, no statistically significant association of fear for flexion or extension on the sagittal plane with directional postural sway measures were
found when the corresponding model comparisons controlling for age and weight were additionally performed. As described above, the results were mostly robust to the deletion of individual participants from the analyses. Nevertheless, Figure 3 (A-H) and Figure 4 (A-H) show that the results seem to be determined largely by a small number of participants, and that many participants reported no or very little fear for movements on both planes. Furthermore, many statistical tests were performed in this analysis, and we did not adapt the significance thresholds to counteract an inflation of the error probability.

Other methodological considerations concern the variables that could be controlled for in this study. The analyses were complex and more robust estimates should be obtained from larger datasets in future studies. For instance, without including age and weight in the models, the effect of fear of the frontal plane on displacement of the sagittal plane would not have been statistically significant. As in the corresponding baseline model, the effect of age was estimated to be negative (Table 3), while a positive effect of age would be expected and was found for other sway outcomes. Further, when flexion and extension were considered separately, the effect of flexion became significant for velocity on both planes. However, the association of age with postural sway is well established (Roman-Liu, 2018), and therefore controlling for the influence of age is important. Additional questions referring to pain and how careful movements would be performed were assessed in the directional type as well. These data were collected, as it is important to discern how movements are avoided and how painful they are experienced (Pincus et al., 2010). Unfortunately, as we aimed to maintain the comparability of the baseline models between the different outcomes and as the available number of participants did not permit to include these estimates in our analysis, we could not control for pain caused by movements in different directions. Although it has been reported that pain did not account for the link found between fears and rather stiff movement of the spine (Christe et al., 2021), future studies should include pain in a directional format as well and not only consider pain on a general level.

4.6 Conclusion

To our knowledge this is the first study exploring the effects of directional fear of movement on postural sway in people with LBP. The presented data suggest that fear of frontal plane trunk movement is positively associated with several measures of postural sway in people with LBP under the investigated stance conditions. We hope these preliminary results can draw further attention to the need to match the level of abstraction of the fear assessment to the level of the movement analysis. Continued work should replicate these results, validate the format of the questions used, and pursue exploration of the mechanisms underlying these observations.
4.7 Acknowledgements

We would like to thank all the participants and the people who supported this study. Tina Wunderlin, Ramon Glättli, Katharina Zahoranszky, Kim Graf and Adrian Stutz helped with performing postural sway assessments with the participants. Ruud Knols and Rick Peters were involved in conducting the primary randomized controlled trial and in the examination of eligibility of study participants. Laura Tüshaus reviewed the custom fear questions. Joanne Lim provided feedback on the manuscript. We received advice regarding the statistical analyses from the Seminar for Statistics at ETH Zurich.

4.8 Funding

This project was funded by the Swiss National Science Foundation (SNSF) as a part of the National Research Program “Big Data” (NRP 75, Grant Nr: 167302).

5 Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

6 Author Contributions

AM, CM, MM, JS and WK planned this work. CM participated in the data collection. AM managed the study, analysed the data, and prepared the first version of the manuscript. AM, MM, JS and WK edited the manuscript. All authors consent to the publication of the manuscript in its current form.

7 References

Alsubaie, A. M., Martinez-Valdes, E., de Nunzio, A. M., and Falla, D. (2021). Trunk control during repetitive sagittal movements following a real-time tracking task in people with chronic low back pain. *Journal of Electromyography and Kinesiology* 57, 102533. doi: 10.1016/j.jelekin.2021.102533.

Bates, D., Mächler, M., Bolker, B., and Walker, S. (2015). Fitting Linear Mixed-Effects Models using lme4. *Journal of Statistical Software* 67, 1–48. Available at: https://arxiv.org/abs/1406.5823v1 [Accessed July 18, 2021].
Berenshteyn, Y., Gibson, K., Hackett, G. C., Trem, A. B., and Wilhelm, M. (2019). Is standing balance altered in individuals with chronic low back pain? A systematic review. Disability and Rehabilitation 41, 1514–1523. doi: 10.1080/09638288.2018.1433240.

Carvalho, F. A., Maher, C. G., Franco, M. R., Morelhão, P. K., Oliveira, C. B., Silva, F. G., et al. (2017). Fear of Movement Is Not Associated With Objective and Subjective Physical Activity Levels in Chronic Nonspecific Low Back Pain. Archives of Physical Medicine and Rehabilitation 98, 96–104. doi: 10.1016/j.apmr.2016.09.115.

Chiarotto, A., Boers, M., Deyo, R. A., Buchbinder, R., Corbin, T. P., Costa, L. O. P., et al. (2018). Core outcome measurement instruments for clinical trials in nonspecific low back pain. Pain 159, 481–495. doi: 10.1097/j.pain.0000000000001117.

Christe, G., Crombez, G., Edd, S., Opsommer, E., Jolles, B. M., and Favre, J. (2021). Relationship between psychological factors and spinal motor behaviour in low back pain: a systematic review and meta-analysis. Pain 162, 672–686. doi: 10.1097/j.pain.0000000000002065.

Costa, L. D. C. M., Maher, C. G., McAuley, J. H., Hancock, M. J., and Smeets, R. J. E. M. (2011). Self-efficacy is more important than fear of movement in mediating the relationship between pain and disability in chronic low back pain. European Journal of Pain 15, 213–219. doi: 10.1016/j.ejpain.2010.06.014.

Gatzounis, R., van Vliet, C., and Meulders, A. (2021). Will that hurt? A contingency learning task to assess pain-expectancy judgments for low back postures. Journal of Behavior Therapy and Experimental Psychiatry 70, 101622. doi: 10.1016/j.jbtep.2020.101622.

Harris, P. A., Taylor, R., Thielke, R., Payne, J., Gonzalez, N., and Conde, J. G. (2009). Research electronic data capture (REDCap)-A metadata-driven methodology and workflow process for providing translational research informatics support. Journal of Biomedical Informatics 42, 377–381. doi: 10.1016/j.jbi.2008.08.010.

Hlaing, S. S., Puntumetakul, R., Wanpen, S., and Boucaut, R. (2020). Balance control in patients with subacute non-specific low back pain, with and without lumbar instability: A cross-sectional study. Journal of Pain Research 13, 795–803. doi: 10.2147/JPR.S232080.
Jacobs, J. v., Roy, C. L., Hitt, J. R., Popov, R. E., and Henry, S. M. (2016). Neural mechanisms and functional correlates of altered postural responses to perturbed standing balance with chronic low back pain. *Neuroscience* 339, 511–524. doi: 10.1016/j.neuroscience.2016.10.032.

Kahraman, B. O., Kahraman, T., Kalemci, O., and Salik Sengul, Y. (2018). Gender differences in postural control in people with nonspecific chronic low back pain. *Gait & Posture* 64, 147–151. doi: 10.1016/j.gaitpost.2018.06.026.

Karayannis, N. v., Smeets, R. J. E. M., van den Hoorn, W., and Hodges, P. W. (2013). Fear of Movement Is Related to Trunk Stiffness in Low Back Pain. *PLoS ONE* 8, e67779. doi: 10.1371/journal.pone.0067779.

Kiers, H., van Dieën, J. H., Brumagne, S., and Vanhees, L. (2015). Postural sway and integration of proprioceptive signals in subjects with LBP. *Human Movement Science* 39, 109–120. doi: 10.1016/j.humov.2014.05.011.

Knechtle, D., Schmid, S., Suter, M., Riner, F., Moschini, G., Senteler, M., et al. (2021). Fear-avoidance beliefs are associated with reduced lumbar spine flexion during object lifting in pain-free adults. *Pain* 162, 1621–1631. doi: 10.1097/j.pain.0000000000002170.

Koch, C., and Hänsel, F. (2019). Non-specific low back pain and postural control during quiet standing-A systematic review. *Frontiers in Psychology* 10, 586. doi: 10.3389/fpsyg.2019.00586.

Leeuw, M., Goossens, M. E. J. B., van Breukelen, G. J. P., Boersma, K., and Vlaeyen, J. W. S. (2007). Measuring Perceived Harmfulness of Physical Activities in Patients With Chronic Low Back Pain: The Photograph Series of Daily Activities—Short Electronic Version. *The Journal of Pain* 8, 840–849. doi: 10.1016/j.jpain.2007.05.013.

Luque-Suarez, A., Martinez-Calderon, J., and Falla, D. (2019). Role of kinesiophobia on pain, disability and quality of life in people suffering from chronic musculoskeletal pain: A systematic review. *British Journal of Sports Medicine* 53, 554–559. doi: 10.1136/bjsports-2017-098673.

Mattheve, T., de Baets, L., Bogaerts, K., and Timmermans, A. (2019). Lumbar range of motion in chronic low back pain is predicted by task-specific, but not by general measures of pain-related fear. *European Journal of Pain* 23, 1171–1184. doi: 10.1002/ejp.1384.
Mazaheri, M., Coenen, P., Parnianpour, M., Kiers, H., and van Dieën, J. H. (2013). Low back pain and postural sway during quiet standing with and without sensory manipulation: A systematic review. *Gait & Posture* 37, 12–22. doi: 10.1016/j.gaitpost.2012.06.013.

Mazaheri, M., Coenen, P., Parnianpour, M., Kiers, H., and van Dieën, J. H. (2014). Competing effects of pain and fear of pain on postural control in low back pain? *Spine (Phila Pa 1976)* 39, E1518–E1523. doi: 10.1097/BRS.0000000000000605.

Meinke, A., Peters, R., Knols, R. H., Swanenburg, J., and Karlen, W. (2022). Feedback on Trunk Movements From an Electronic Game to Improve Postural Balance in People With Nonspecific Low Back Pain: Pilot Randomized Controlled Trial. *JMIR Serious Games* 10, e31685. doi: 10.2196/31685.

Meinke, A., Peters, R., Knols, R., Karlen, W., and Swanenburg, J. (2021). Exergaming Using Postural Feedback From Wearable Sensors and Exercise Therapy to Improve Postural Balance in People With Nonspecific Low Back Pain: Protocol for a Factorial Pilot Randomized Controlled Trial. *JMIR Research Protocols* 10, e26982. doi: 10.2196/26982.

Mikkonen, J., Leinonen, V., Kaski, D., Hartvigsen, J., Luomajoki, H., Selander, T., et al. (2022). Postural sway does not differentiate individuals with chronic low back pain, single and multisite chronic musculoskeletal pain, or pain-free controls: a crosssectional study of 229 subjects. *The Spine Journal* 00, in press. doi: 10.1016/j.spinee.2022.04.013.

Mok, N. W., Brauer, S. G., and Hodges, P. W. (2004). Hip strategy for balance control in quiet standing is reduced in people with low back pain. *Spine(Phila Pa 1976)* 29, E107-12. doi: 10.1097/01.brs.0000115134.97854.c9.

Nieuwenhuis, R., te Grotenhuis, M., and Pelzer, B. (2012). Influence.ME: Tools for detecting influential data in mixed effects models. *R Journal* 4, 38–47. doi: 10.32614/rj-2012-011.

Nordstoga, A. L., Meisingset, I., Vasseljen, O., Nilsen, T. I. L., and Unsgaard-Tøndel, M. (2019). Longitudinal associations of kinematics and fear-avoidance beliefs with disability, work ability and pain intensity in persons with low back pain. *Musculoskeletal Science and Practice* 41, 49–54. doi: 10.1016/j.msksp.2019.03.008.

Osumi, M., Sumitani, M., Otake, Y., Nishigami, T., Mibu, A., Nishi, Y., et al. (2019). Kinesiophobia modulates lumbar movements in people with chronic low back pain: a kinematic analysis of
lumbar bending and returning movement. *European Spine Journal* 28, 1572–1578. doi: 10.1007/s00586-019-06010-4.

Pincus, T., Smeets, R. J. E. M., Simmonds, M. J., and Sullivan, M. J. L. (2010). The fear avoidance model disentangled: Improving the clinical utility of the fear avoidance model. *The Clinical Journal of Pain* 26, 739–746. doi: 10.1097/AJP.0b013e3181f15d45.

Portney, L. G., and Watkins, M. P. (1993). *Foundations of Clinical Research: applications to Practice*. Norwalk: Appleton & Lange.

Prieto, T. E., Myklebust, J. B., Hoffmann, R. G., Lovett, E. G., and Myklebust, B. M. (1996). Measures of postural steadiness: Differences between healthy young and elderly adults. *IEEE Transactions on Biomedical Engineering* 43, 956–966. doi: 10.1109/10.532130.

Revelle, W. (2021). psych: Procedures for Psychological, Psychometric, and Personality Research. Available at: https://cran.r-project.org/package=psych.

Roman-Liu, D. (2018). Age-related changes in the range and velocity of postural sway. *Archives of Gerontology and Geriatrics* 77, 68–80. doi: doi.org/10.1016/j.archger.2018.04.007.

Ruhe, A., Fejer, R., and Walker, B. (2010). The test–retest reliability of centre of pressure measures in bipedal static task conditions – A systematic review of the literature. *Gait & Posture* 32, 436–445. doi: 10.1016/j.gaitpost.2010.09.012.

Ruhe, A., Fejer, R., and Walker, B. (2011). Center of pressure excursion as a measure of balance performance in patients with non-specific low back pain compared to healthy controls: A systematic review of the literature. *European Spine Journal* 20, 358–368. doi: 10.1007/s00586-010-1543-2.

Rusu, A. C., Kreddig, N., Hallner, D., Hülsebusch, J., and Hasenbring, M. I. (2014). Fear of movement/(Re)injury in low back pain: confirmatory validation of a German version of the Tampa Scale for Kinesiophobia. *BMC Musculoskeletal Disorders* 15, 280. doi: 10.1186/1471-2474-15-280.

Shanbehzadeh, S., Salavati, M., Talebian, S., Khademi-Kalantari, K., and Tavahomi, M. (2018). Attention demands of postural control in non-specific chronic low back pain subjects with low and high pain-related anxiety. *Experimental Brain Research* 236, 1927–1938. doi: 10.1007/s00221-018-5267-6.
Sung, W., Abraham, M., Plastaras, C., and Silfies, S. P. (2015). Trunk motor control deficits in acute and subacute low back pain are not associated with pain or fear of movement. *The Spine Journal* 15, 1772–1782. doi: 10.1016/j.spinee.2015.04.010.

van Dieën, J. H., Reeves, N. P., Kawchuk, G., van Dillen, L. R., and Hodges, P. W. (2019). Motor Control Changes in Low Back Pain: Divergence in Presentations and Mechanisms. *Journal of Orthopaedic and Sports Physical Therapy* 49, 370–379. doi: 10.2519/jospt.2019.7917.

Vlaeyen, J. W. S., and Crombez, G. (1999). Fear of movement/(re)injury, avoidance and pain disability in chronic low back pain patients. *Manual Therapy* 4, 187–195. doi: 10.1054/math.1999.0199.

Wertli, M. M., Rasmussen-Barr, E., Weiser, S., Bachmann, L. M., and Brunner, F. (2014). The role of fear avoidance beliefs as a prognostic factor for outcome in patients with nonspecific low back pain: A systematic review. *The Spine Journal* 14, 816-836.e4. doi: 10.1016/j.spinee.2013.09.036.

Winter, D. (1995). Human balance and posture control during standing and walking. *Gait & Posture* 3, 193–214. doi: 10.1016/0966-6362(96)82849-9.

Woby, S. R., Roach, N. K., Urmston, M., and Watson, P. J. (2005). Psychometric properties of the TSK-11: A shortened version of the Tampa Scale for Kinesiophobia. *Pain* 117, 137–144. doi: 10.1016/j.pain.2005.05.029.

Wu, A., March, L., Zheng, X., Huang, J., Wang, X., Zhao, J., et al. (2020). Global low back pain prevalence and years lived with disability from 1990 to 2017: estimates from the Global Burden of Disease Study 2017. *Annals of Translational Medicine* 8, 299. doi: 10.21037/atm.2020.02.175.

Zhang, C., Zhang, Z., Li, Y., Feng, C., Meng, H., Gao, Y., et al. (2020). Pain catastrophizing is related to static postural control impairment in patients with nonspecific chronic low back pain: A cross-sectional study. *Pain Research and Management* 2020, 9629526. doi: 10.1155/2020/9629526.