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Research Article

Regain balance: Recovery of postural perturbations of people with and without chronic low back pain

Abstract

Background: Chronic low back pain (CLBP) seems to influence adjustment of posture. The application of external disturbances is used to gain a better understanding of movement strategies and their possible alterations to restore postural balance in people with CLBP.

Objective: This cross-sectional observational study aimed to investigate the kinematic quality of postural recovery to sudden lateral perturbations between people with and without CLBP.

Methods: Three types of perturbations at two amplitudes applied over a hand held grip were used to test adaptive postural control in an upright standing position. For analyzing the kinematic quality of postural recovery, the range of motion, the time to regain balance and the number of postural adjustments of the shoulder- and pelvis angle were examined.

Results: People with CLBP needed reduced time for stabilization and reduced number of adjustments of the pelvis angle. These findings are linked to a specific character of applied perturbations. No differences were found for the range of motion between the two groups.

Conclusion: Among the different offered types of disturbances, the sudden loading perturbations that could cause a possible buckling of the spinal column, led to a limited movement response of the people with CLBP. It seems that this reaction depends on the level of loading which activates stress induced adjustments.

Introduction

The restoration of postural equilibrium is a permanent task of human posture. Especially perturbations challenge the motor control system to manage the interaction of stability and mobility. For maintaining stance the categorized hip and ankle strategies are widely accepted [1–3]. The hip strategy is used in the case of large and rapid center of mass (COM) motion producing torque on the hip joint. Especially perturbations of the COM in the mediolateral direction will be stabilized using the hip strategy because of anatomical limitations at the ankle and the mechanical chain of bottom, knee and hip [4].

It is evident that people with chronic low back pain (CLBP) have disturbed spinal movement and compromised balance [5–8]. Looking at the ground reaction force during sudden weight drop into a frontal held box individuals with CLBP took longer to recover postural stability [9]. The longer recovery period was related to a delayed initiation of lumbar spine flexion in the anterior direction [9]. The authors associated this effect to a change of stiffness in the upper limb of the patients with CLBP. Instead of flexing the trunk the CLBP group preferred the rotation around the ankles – so called ankle strategy.

Since the center of pressure (COP) displacement in the mediolateral direction is more suitable to predict the falling risk in the elderly than in the anterior-posterior direction. The mediolateral balance control is also in the focus of CLBP diseases [10]. Multi-directional support surface translation was used to quantify motor control impairments in people with CLBP [6,11]. Henry et al., 2006 investigated the COP and COM displacements during unexpected surface translation in one of 12 directions (sagittal and frontal plane) between people with CLBP and healthy controls (HC) [6]. No significant differences were identified in the magnitudes of COP and COM displacements in the mediolateral directions. However, the patients with CLBP had later onset of initial COP displacement and an earlier peak displacement in the COM. The authors hypothesized that the individuals with CLBP were stiffer prior to the perturbation onset. Also Jones et al., found that patients

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with CLBP using a trunk stiffening strategy in response to mediolateral surface translations [11]. Appropriate to this finding, previous studies identified increased level of baseline [12] and perturbation-induced co-activation of trunk muscles [13,14].

Because of the indication of the trunk stiffening strategy of patients with CLBP we hypothesized that patients restrict the movement at the hip during multiple unexpected lateral perturbations and this would be associated with alterations in restoring equilibrium position. Therefore, the aim of this study was to investigate the kinematic quality of postural recovery to lateral perturbations applied over a hand held grip between people with CLBP and HC. The kinematic quality was defined by the range of motion, the time to regain balance, the number of postural adjustments of shoulder- and pelvis angle. A further aim was to investigate whether a deficit in postural recovery depends on the character of the specific perturbation.

Methods

Subjects

We examined a cohort of 20 female subjects in a cross-sectional observational study. The case group (CLBP) consisted of ten patients with chronic low back pain. The control group (HC) consisted of ten subjects of healthy controls who are assigned to each member of the CLBP group (matched according to age, weight, stand width and hip width, Table 1) and had not suffered from any low back pain or spinal alignment in the last year. The inclusion criteria for patients were evaluated by experts (radiologist and pathophysiologist). Patients were only included if they had low back pain for a minimum duration of 2 years, had no disc pathology and had no symptoms of nerve root compression. Patients of CLBP group reported the level of low back pain and completed an abbreviated version of the health survey questionnaire (SF 36, [15], Table 1). All subjects were invited to take part on voluntary basis and signed a privacy statement declaring that the collected data will be stored and processed in computers and published in a pseudonymised manner for scientific purposes. In addition, all subjects were introduced in-depth to the experimental setup as well as potential risks. All of them agreed to the protocol and gave written informed consent in accordance with the declaration of Helsinki. The ethics committee of the University of Jena approved the study in accordance with the declaration of Helsinki (0558-11/00) as a statement of ethical principles for medical research involving human subjects.

Table 1: Subject anthropometric parameters (N - number of participants, BMI - body mass index), SF 36 scores and pain intensity by group mean (standard deviation). No significant differences of the anthropometric parameters were determined between matched groups. SF 36 scores represented current state of 0-100 rating health scale (0 - worst possible health to 100 - best health). Pain intensity scores represented level of low back pain on a visual analog scale ranked from “no pain” (0) to “maximum pain” (10).

Group	HC	CLBP
N	10	10
Age [years]	39.7 (14.0)	40.6 (11.6)
BMI [kg/cm²]	22.8 (2)	22.5 (2)
Stand width [mm]	254 (68)	248 (30)
Hip width [mm]	381 (16)	375 (21)
Physical functioning	--	81.8 (11.7)
Role limitations due to physical health	--	75.0 (30.6)
Bodily pain	--	53.7 (10.6)
General health perceptions	--	73.3 (15.8)
Vitality	--	53.5 (14.1)
Social functioning	--	78.7 (17.7)
Role limitations due to emotional problems	--	81.4 (29.3)
Mental health	--	64.8 (19.1)
Pain intensity prior experiment	--	3.1 (2.1)
Pain intensity last four weeks	--	3.4 (1.6)

Experimental setup

The starting position was defined as a neutral upright position with the feet at shoulder width and a grip in the hand. The participants were asked to stay erect while looking straight ahead. Based on this position six different disturbances in a randomized sequence were applied over the hand held grip during a 35 s trial [16]. The grip was connected via a rope entailing a force sensor (1000 N, Biovision, Germany) to a servomotor (FLP 31/0125-30AA232, Stromag Elektronik GmbH, Germany). The latter was controlled by a personal computer (VECWIN, Stromag Elektronik GmbH, Germany). The torque controlled servomotor generated disturbances containing unloading perturbations, loading perturbations and impulse perturbations (Figure 1). After each perturbation the participants took a self-selected upright standing posture which was not predefined by the examiner. A shift in the stand width or the lift of a foot during a trial was not allowed. A subject experienced five trials in a row (with 30 s breaks between the trials) for each side (left, right). Markers (12 mm) were attached to the ipsilateral (IPS) and contralateral (CON) acromion and the spina iliaca posterior superior (SIPS) and movements were measured using six 3D-infrared cameras (240 Hz, Qualisys, Göteborg, Sweden).

Data analysis

For analyzing the kinematic quality of postural recovery the range of motion, the time to regain balance, the number of postural adjustments of shoulder- and pelvis angle were calculated for each perturbation. Raw data were filtered using a third order low-pass Butterworth filter at 20 Hz cutoff frequency.

Shoulder- and pelvis angle: The shoulder- and pelvis angle (see formula 1-2) were calculated in the frontal plane.

$$shoulder\,angle = atan\,\left(\frac{acromion\,IPS\,vertical - acromion\,CON\,vertical}{acromion\,IPS\,mediolateral - acromion\,CON\,mediolateral}\right) \times \frac{180}{\pi} \qquad (1)$$

$$pelvis\,angle = atan\,\left(\frac{SIPS\,IPS\,vertical - SIPS\,CON\,vertical}{SIPS\,IPS\,mediolateral - SIPS\,CON\,mediolateral}\right) \times \frac{180}{\pi} \qquad (2)$$

Range of Motion: Range of motion of the angles was calculated by the maximum to the minimum excursion (Figure 2A).

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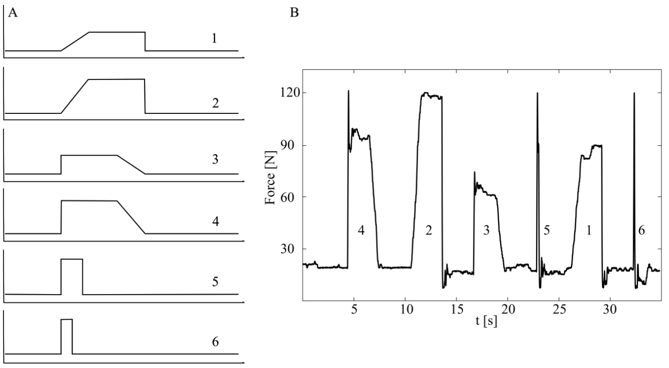

Figure 1: Applied perturbations. (A) shows the perturbations in a simplified model. Perturbation 1 and 2 were unloading perturbations. The servomotor generated within 1 s a steadily increasing torque until the level of 90 N - perturbation 1 and 120 N - perturbation 2. After holding the level for two seconds the torque decreased rapidly. Perturbation 3 and 4 were loading perturbations. The servomotor generated within .14 s a fast increasing torque of 80 N - perturbation 3 and 120 N - perturbation 4. The settle down force of 70 N - perturbation 3 and 100 N - perturbation 4 decreased after 2 s to the base level. Perturbation 5 and 6 were impulse perturbations. The torque maximum of 120 N was reached after .1 s. Subsequently the torque decreased and had reached the base level after .2 s - perturbation 6 and after .3 s - perturbation 5. (B) shows the measured force of the perturbations in the rope of the grip for a selected trial. For each trial the six perturbations occurred in a randomized order.

Time to regain balance: For the calculation of the time to regain balance the angle velocity (differentiation of excursion of shoulder- and pelvis angle) was analyzed. The absolute values of the angle velocity were compared between the level of baseline (mean from 100 ms to 300 ms before the onset of the applied perturbation plus three standard deviations) and the level of perturbed standing. The specific point in time to regain balance after the perturbations was defined as the angle velocity fell short of the level of baseline + 3 SD for 100 ms (Figure 2B) [9,17].

Number of postural adjustments: The number of postural adjustments was calculated as the number of times the angle velocity crossed zero in the period of the onset of the applied perturbations until the calculated time to regain balance (Figure 2C) [9].

Statistics

The mean value for each calculated parameter of postural recovery (the range of motion, the time to regain balance and the number of postural adjustments of shoulder- and pelvis angle) of all ten trials per subject were stored in IBM SPSS Statistics 20.0 (IBM SPSS Statistics Inc., Chicago, IL). Differences between the CLBP group and the HC group were tested with the Mann-Whitney U test (chronic low back pain grouping as independent variable and the parameter of postural recovery as dependent variable).

Because of multiple statistical comparison the P value were adjusted to < .0083 (the Bonferroni adjustment (α/k) – P value of .05 divided by 6 (number of comparisons per perturbation)).

Results

Range of motion

For all analyzed perturbations (1 to 6) there were no significant differences in pelvis- and shoulder angle between the CLBP and HC group (Table 2).

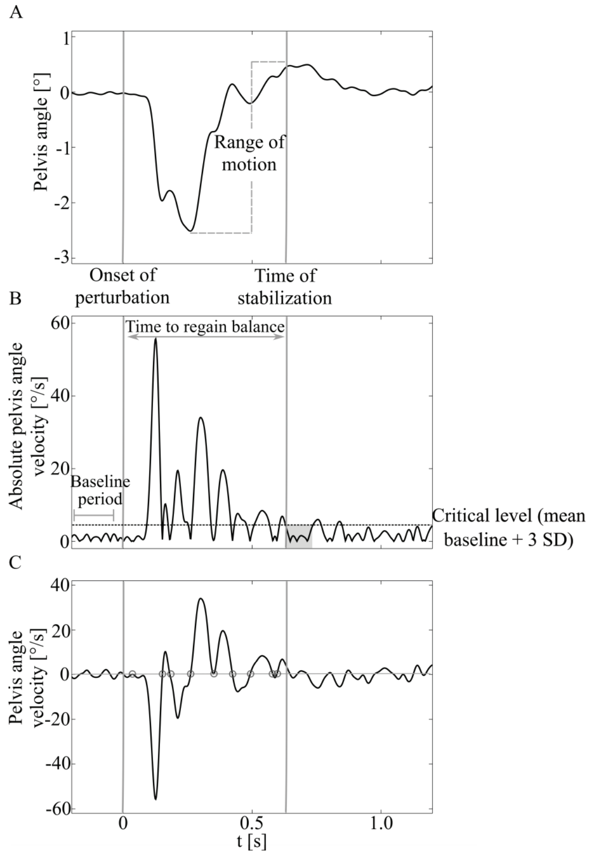

Figure 2: Determination of parameters of postural recovery of pelvis angle for a selected trial of perturbation 6. The vertical solid grey lines represent the time to regain balance. The force sensor signal of the hand held grip was used to define the onset of the perturbations. (A) shows the range of motion with the local maximum and minimum of pelvis angle excursion. (B) shows the absolute pelvis angle velocity. The calculated length of time to regain balance based on this signal. The gray box represents the minimum duration of 100 ms under the level of baseline. (C) shows the number of adjustments from onset (t = 0) to the time of stabilization highlighted in grey circles.

Time to regain balance

For perturbation 6, the time to regain balance was significantly shorter for the pelvis angle in CLBP group (Median = 631 ms) than for the pelvis angle in HC group (Median = 716 ms, Table 3), U = 10.0, P = .004, Z = -3.024.

For perturbation 5, the time to regain balance was tendential shorter (non-significant trend) for the pelvis angle in CLBP group (Median = 617 ms) than for the pelvis angle in HC group (Median = 752 ms, Table 3), U = 10.0, P = .01, Z = -3.024.

No significant differences for the time to regain balance in the shoulder angle were identified between the groups.

Number of postural adjustments

For perturbation 6, the number of postural adjustments were tendential fewer (non-significant trend) for the pelvis angle in CLBP group (Median = 10) than for the pelvis angle in HC group (Median = 12, table 4), U = 23.0, P = .04, Z = -2.05.

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Table 2: Range of motion of pelvis- and shoulder angle in degrees (median and range) for perturbation 1 to 6 and groups.

Perturbation	Pelvis angle			Shoulder angle		
	HC	CLBP	P-value[a]	HC	CLBP	P-value[a]
1	3.0 (2.0 - 5.8)	2.6 (1.9 - 6.5)	n.s.	11.9 (9.8 - 14.8)	11.8 (8.0 - 14.2)	n.s.
2	4.1 (3.1 - 7.4)	3.5 (2.4 - 8.5)	n.s.	15.1 (13.7 - 18.5)	15.7 (8.8 - 18.7)	n.s.
3	2.3 (1.7 - 3.8)	1.8 (1.4 - 4.3)	n.s.	8.0 (7.0 - 9.3)	7.0 (3.4 - 9.7)	n.s.
4	4.4 (3.2 - 6.2)	3.7 (2.6 - 6.8)	n.s.	15.4 (11.5 - 21.9)	15.4 (7.6 - 16.9)	n.s.
5	4.5 (3.3 - 6.2)	4.0 (2.8 - 7.0)	n.s.	15.5 (11.8 - 17.4)	15.4 (6.7 - 17.5)	n.s.
6	4.3 (3.1 - 5.0)	3.2 (2.5 - 5.4)	n.s.	14.1 (9.6 - 16.3)	12.9 (5.1 - 14.3)	n.s.

[a] n.s., not significant.

Table 3: Time to regain balance of pelvis- and shoulder angle in milliseconds (median and range) for perturbation 1 to 6 and groups.

Perturbation	Pelvis angle			Shoulder angle		
	HC	CLBP	P-value[a]	HC	CLBP	P-value[a]
1	3970 (3802 - 4180)	3909 (3770 - 4438)	n.s.	4058 (3930 - 4236)	4072 (3822 - 4410)	n.s.
2	4087 (3903 - 4246)	4024 (3896 - 4420)	n.s.	4180 (3907 - 4354)	4197 (3877 - 4540)	n.s.
3	3067 (3002 - 3200)	3060 (3017 - 3175)	n.s.	3415 (3265 - 3563)	3493 (3312 - 3631)	n.s.
4	3067 (3011 - 3318)	3090 (3017 - 3371)	n.s.	3291 (3153 - 3436)	3335 (3170 - 3623)	n.s.
5	752 (541 - 950)	617 (557 - 784)	.01	926 (815 - 1150)	1003 (591 - 1091)	n.s.
6	716 (561 - 861)	631 (500 - 680)	.004	922 (782 - 965)	877 (666 - 1057)	n.s.

[a] n.s., not significant.

Table 4: Number of postural adjustments of pelvis- and shoulder angle (median and range) for perturbation 1 to 6 and groups.

Perturbation	Pelvis angle			Shoulder angle		
	HC	CLBP	P-value[a]	HC	CLBP	P-value[a]
1	80 (63 - 93)	82 (77 - 88)	n.s.	27 (18 - 32)	30 (21 - 37)	n.s.
2	76 (59 - 94)	80 (66 - 95)	n.s.	24 (21 - 34)	30 (15 - 40)	n.s.
3	52 (48 - 64)	54 (41 - 69)	n.s.	15 (13 - 24)	19 (12 - 25)	n.s.
4	50 (43 - 61)	54 (44 - 60)	n.s.	17 (9 - 20)	15 (8 - 20)	n.s.
5	11 (8 - 13)	9 (5 - 11)	n.s.	3 (3 - 4)	3 (2 - 5)	n.s.
6	12 (9 - 15)	10 (7 - 12)	.04	3 (2 - 4)	3 (2 - 5)	n.s.

[a] n.s., not significant.

There were no significant differences for the number of postural adjustments in the shoulder angle between the groups.

Discussion

We identified significant differences in the kinematic quality of postural recovery to lateral perturbations between people with CLBP and HC. Differently as hypothesized there were no differences in the range of motion of shoulder- and pelvis angle between the groups. Whereas regarding to the parameters of time to regain balance and number of postural adjustments, we found that people with CLBP needed reduced time for stabilization and reduced numbers of adjustments for the pelvis angle. These latter findings are linked to a specific character of applied perturbations (perturbation 6). Therefore the postural recovery during perturbation 6 is in the focus of the discussion.

Range of motion

The parameter range of motion describes the maximum excursion of the pelvis- and shoulder angle during the stabilization process. The first local extreme point (minimum for perturbation 6) of the range of motion calculation occurred in the primary phase of the movement reaction when the first reversal point was reached (Figure 3 A, D). The initial phase is dominated by an immediate response of the system control. At that time mainly passive mechanics damps the sudden load [18,19].

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After the maximal deflection was reached, the next step is dominated by the return of the rotated and translated body segments to the initial position. Often the initial position was overshoot. These overshooting indicated the second local extreme point in the range of motion calculation. For perturbation 6 the extremes of pelvis- and shoulder angle were reached on average within 500 ms (Figure 3 A, D).

Within the time frame of the range of motion calculation a plurality of movement strategies (passive- and active damping, hip strategy and repositioning) are involved [18–20]. However the range of motion parameter gives no information of the specific duration of the current movement strategy or the points in time of the local extrema. This could be a reason why the range of motion parameter is not precise enough to distinguish between people with CLBP and HC for this experiment. Otherwise it could be an indication that the general movement response (referred to the phases of the movement pattern) was executed in the same manner of people with CLBP and HC.

A similarity in the movement patterns between CLBP and controls was observed as well during multi-directional platform perturbations [6,11]. While Jones et al., 2012 identified reduced peak trunk torques in people with CLBP in the frontal plane [11], Henry et al. 2006 identified in an earlier experiment no significant differences in the magnitude of the center of mass during platform perturbations in the same direction [6]. However, in both studies the peak latency was earlier for the people with CLBP and was associated with a trunk stiffening strategy.

Time to regain balance

Following the trunk stiffening strategy the identified reduced time to regain balance for the pelvis angle of perturbation 6 in people with CLBP support this theory. One explanation for this finding could be that subjects of the CLBP group aimed to reduce the velocity at the pelvis because of fear of movement or pain. For example, people with CLBP chose lower velocity in movements then HC during voluntary movement tasks [21,22]. It stands to reason that in reactive tasks this cohort connects high velocities of body segments with a potential loss of equilibrium [21] or re-injury [23] and therefore aiming to reduce loads. On the other hand a shorter time of stabilization of the pelvis could be linked to an increased damping during lateral perturbation. In contrast to this assumption, Hodges et al., 2008 found lower damping in patients with low back pain doing trunk perturbation in the sagittal plane [24]. Additionally, the authors identified increased trunk stiffness for the patient group as a possible consequence of a compensation strategy. Despite the group differences in damping and stiffness, there was no difference in the duration of the trunk displacement. In contrast to the present study the time frame was set from the onset of the perturbation until the maximum of trunk displacement (around 388 ms for forward perturbation and around 343 ms for backward perturbation). The repositioning movement (from the maximum displacement to the start position) was not investigated in contrast to this study.

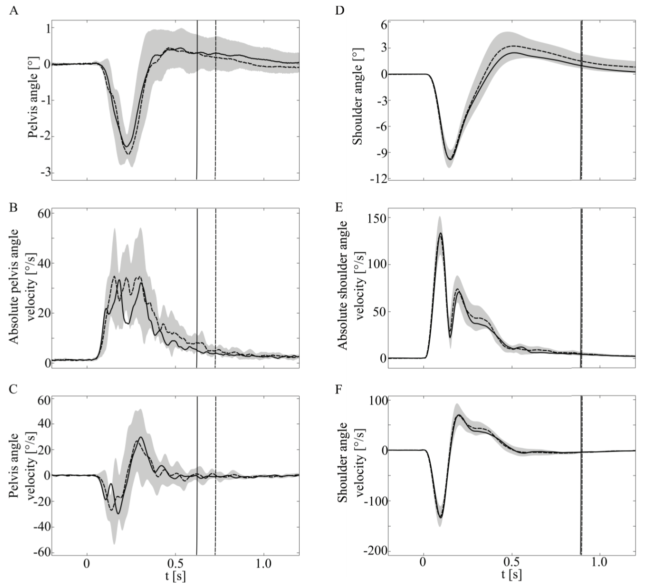

Figure 3: Time course of parameters of postural recovery of pelvis angle (A-C) and shoulder angle (D-F) for perturbation 6. Dashed lines reveal the mean of participants in HC group and the grey shaded areas reveal the standard deviation. Solid lines represent the mean of participants in CLBP group. The vertical solid lines indicate the mean of time to regain balance of CLBP group. The vertical dashed lines indicate the mean of time to regain balance of HC group.

Following the movement strategy discussion above, the proprioceptive feedback control could be suppressed in the beginning of the response of the applied perturbation [25]. It is not completely clear how position feedback and velocity feedback operate afterwards. Niu et al., 2010 assumed that the velocity feedback control is activated in the middle and position feedback in the late during reaching arm movements [25]. An altered velocity feedback control could result in a reduced time to regain balance in people with CLBP of this study.

Another explanation for an earlier time to regain balance of CLBP group could be an increased stiffness due to an increased level of co-contraction of muscles. In a study that used a comparable impulse perturbation (perturbation 6) generated by an identical servomotor as in the present study there was no evidence for a co-activation strategy [26], but identified delayed reflex responses with unadapted reflex amplitudes in the CLBP group [26] could be linked to an altered muscle response which resulted in a reduction of the pelvis velocity. Other experimental studies found an increased co-activation for people with CLBP may be applied as a compensation strategy for limitations in the stabilizing system [27,28] or as an emergency strategy to regain stability [29].

Number of postural adjustments

The number of postural adjustments represents major direction changes of the shoulder- and pelvis angle. From a mechanical point of view a stiffer body system with greater damping leads to a reduced number of postural adjustments during identical application of force. The results show people with CLBP needed fewer adjustments of pelvis angle (by trend, P = .04) then HC for perturbation 6. It seems that people with CLBP tend to use direction changes of the pelvis less frequently than HC during this specific perturbation.

In contrast to a fewer number of postural adjustments in this cohort, Mok et al., 2011 identified an increased number of adjustments in response to external perturbation applied by a weight drop into a frontal hand helded box [9]. The authors emphasized that people with CLBP had delayed onset of lumbar flexion, which is combined with increased time and number of postural adjustments for stabilization. One reason for the differences could be that people with CLBP preferred to use the ankle strategy if it is possible [6]. During lateral perturbation as in this study the amount of stabilization through the ankle strategy is much smaller [4].

To check if the number of postural adjustments correlated with the time to regain balance a spearman correlation was calculated. We found a significant positive correlation between the time to regain balance and the number of postural adjustments in pelvis angle for perturbation 6 ($r^2 = .743$, $P < .001$). This positive correlation describes that a longer time to regain balance was associated with a higher number of postural adjustments.

Total angle distance of pelvis and shoulder

As consequence of the detected correlation and the associated risk of potential overestimation of the parameters time to regain balance and number of postural adjustments, a more independent approach to quantify stabilization of posture was pursued.

The calculation of the total angle distance of pelvis and shoulder for perturbation 6 describe the cumulated overall movement (Figure 4). A main finding was that people with CLBP covered a significant lower total distance of the pelvis angle within the reposition movement (Figure 4, t3) and beyond that (Figure 4, t4). The shoulder angle was not affected by this.

Clarifying the contributions of proprioceptive feedback (velocity, position and force) [30] the temporal shift from passive movement strategies in the very beginning of the response [19] to an active response, influence by proprioceptive feedback control, could explain this findings.

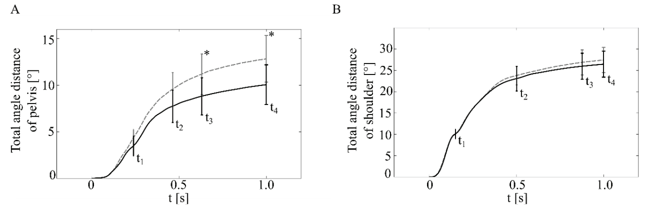

Figure 4: Mean of cumulated total angle distance of pelvis (A) and shoulder (B) of perturbation 6 (grey = HC group, black = CLBP group, error bars = standard deviation). For analyzing group differences of total angle distance, different time points were used (t1 = maximum excursion of initial position of CLBP group, t2 = maximum overshooting of initial position of CLBP group, t3 = time to regain balance of CLBP group and t4 = no further movement expected). The results of a two-way repeated measures ANOVA showed that there was a significant main effect of grouping variable (chronic low back pain) on the average number of total angle distance of pelvis (F(1,18) = 6.57, P = .02). Bonferroni post hoc tests showed statistical differences (*, P ≤ .05) between the groups in total angle distance of pelvis at t3 (CLBP (mean = 8.8°; SD = 2.0°), HC (mean = 11.2°; SD = 2.2°)) and t4 (CLBP (mean = 10.1°; SD = 2.1°), HC (mean = 12.8°; SD = 2.5°)). For these comparisons participants of the CLBP group covered a significant lower total angle distance.

Niu 2010 assumed proprioceptive feedback control is suppressed in the beginning during reaching arm movements [25]. The authors suggest that in the middle phase of the movement the velocity feedback and the position feedback in the late are dominantly active [25]. According to this assumption, the differences in the total angle distance of pelvis could indicate a disturbed proprioception of people with CLBP.

Others studies show that there is some evidence that people with CLBP have reduced spinal proprioception [31,32].

There is reason to suspect that a shorter time to regain balance, a tendentially reduced number of postural adjustments and a lower total angle distance of the pelvis in people with CLBP could be linked to a deficit in repositioning. It cannot be ruled out that the previous results are due to a greater deviation from the initial standing position of people with CLBP. For example, the people with CLBP could remain in a more lateral bent position after perturbation 6, while the HC completely return to the upright starting position. According to the velocity approach applied in this study, people with CLBP are considered as stabilized, but they still would not have completely regained their initial position with respect to the posture.

Perturbation-specific differences

The comparison of the kinematic quality showed only significant differences for perturbation 6 (impulse perturbation) between people with CLBP and HC. A look at the technical characteristics of the three different perturbations, each with stronger/shorter and weaker/longer characteristics, in Figure 1 shows that the shortest impact is generated for perturbation 6.

One assumption of the identified perturbation-specific kinematic differences could be, that they occur especially at particularly high loads on the spine. During loading perturbations (perturbation 3-6) there is a potential risk of the spine buckling [33]. Unloading perturbations, like perturbation 1 and 2, are not linked to this risk. Wagner et al., 2005 analyzed the musculoskeletal support of lumbar spine stability of ten students by using almost identical perturbations generated by a comparable servomotor [34]. While for unloading perturbations the preload induced a pre-activation of trunk muscles and thus prepares the trunk, the trunk muscles, on the other hand, were not prepared during sudden loading perturbations [34]. This fundamental difference speaks for the results found. However, it does not explain why there are differences between the groups in the kinematics for perturbation 6 and not for perturbation 4 for example, although the applied maximum torques (120 N) are identical.

We assume that the short application time of perturbation 6 (200 ms) is linked to high shift in acceleration of body segments which results in an increased agonistic and antagonistic trunk muscle activation. It is possible that this short-term high load will lead to a muscular activation threshold that limited the movement and stiffend the lumbar spine. A similar conclusion drew Hodges and Richardson 1999 [35]. In an investigation comparing trunk muscle recruitment during different speeds of arm movement between people with and without low back pain, they found no differences at slower speed arm movements. However during faster arm movements the muscle recruitment differs between the groups. The Authors traced these effects back to a velocity threshold.

Limitations

The results of this study are based on a matched dataset of ten subjects of HC who are assigned to each patient with CLBP. Patients with CLBP are usually more heterogeneous than HC [26]. Therefore, conclusions on the disease are not free from bias. Although this cross-sectional observational study was adjusted with regard to important anthropometric parameters (Table 1), it cannot be excluded that differences in the strength level in certain muscle groups, the intra- and intermuscular coordination and the muscle fiber type distribution have an influence on the kinematic reaction. In addition, the velocity approach applied in this study and the cumulated total angle distance by means of kinematic parameters are suitable for identifying group differences, but not to determine the difference in posture between the initial and end position. Finally, the examiner did not predefined the stabilized end position. The participants took a self-selected upright standing posture after each perturbation. A shift in the stand width or the lift of a foot during a trial was generally not allowed.

Conclusion

Not all of the applied external perturbations are accompanied by a kinematically measurable difference of postural recovery between people with and without CLBP. However, sudden loading perturbations entailing the shortest impact (perturbation 6) led to a shorter time to regain balance and a reduced number of adjustments of the pelvis angle in CLBP group. It seems that this reaction depends on a level of loading, which activates stress induced adjustments. A reduced time to regain balance and a reduced number of adjustments could be linked to an increased stiffness and may aid in protection of spinal structures. However, these findings could also be result of the costs of a larger deviation from the initial position and thereby lead to a changed posture.

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